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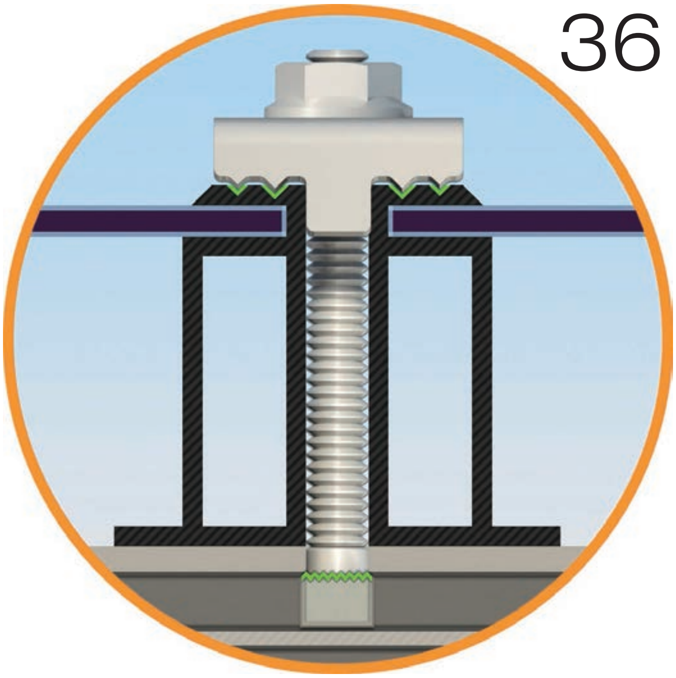
contents

28



36

Main Features

16

On the Cover

Ashland, Oregon, homeowners Steve and Buffie Asher prove that you can live large in a small space.

Photo by Ben Root

contents

Up Front

44

More Features

52

In Back

Photos (clockwise, from opposite page, bottom right): Courtesy Rainforest Connection; courtesy IronRidge; Ben Root; courtesy PHIUS; courtesy MidNite Solar

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Building Resilience
Beyond Renewable Energy

Here in Oregon, weird weather seems to be the norm. Last year, our local ski hill was closed due to scanty snow. So far this winter, it has endured another rough season—opening for awhile, then closing when warm rains melted the snow, then reopening after temperatures finally dropped and abundant rain fell on the valley floor. Last summer was long and hot, and full of fire-fighting drama, with bloated tanker planes making the local airport their home. However, it wasn't as smoke-choked as the previous summer, when we relocated to another county for three weeks to escape the poor air quality.

But it's not just the weather that's wacky. It's February as I write this, and the leopard lilies are already poking up through the pasture; some of the Indian warrior in the forest are blooming. It all makes me wonder what we're in for next, and has me turning a critical eye toward the systems at my homestead—energy, water, shelter, food—and pondering how I could improve them.

Years ago, sustainability was a buzzword that was tossed around as an end goal for systems, whether they be agricultural, architectural, social, or economic. But today's challenges may be better met with resilience, in which systems can respond, adapt, and survive a hiccup or more long-term condition, while maintaining their integrity and function.

For example, while we have a relatively "sustainable" electricity system—a batteryless grid-tied PV array sized to meet almost all of our household's energy needs—what happens when the grid goes down? Without batteries—um, absolutely nothing. That is, we have no way of tapping into the electricity that our PV system could still be producing. While ecologically motivated, the bottom line is that our choice of relying on one energy source to serve the bulk of our loads doesn't lend itself to resilience. Certainly, we can implement other sources to satisfy some of our daily needs, such as cooking in the solar oven or atop the wood heater. But for other needs—say, water pumping—we are SOL (and that's not a fancy abbreviation for solar).

It's obvious to me that a more diversified energy system at our homestead would make it more resilient. Perhaps that means a PV-direct water-pumping system that moves water from our well to a large cistern that gravity-feeds water to our house. Maybe it means a wood cookstove in our kitchen that's also equipped with a water jacket to heat our domestic water.


©istockphoto.com/Tokle

Perhaps I find an old drum washer and a bike, and make my own pedal-powered clothes washer. Maybe we add a small battery bank (and the requisite equipment) to our system.

Rainwater catchment. Wood cookstoves. Solar air and water heaters. Backup batteries. Doing more with less, in more insulated and smaller solar spaces. There are many ways to build in resilience, and each path will be different depending on your household's location and needs. But, no matter what, it's certain to me that the times they are a-changin', and building in some homestead resilience—beyond renewable electricity—is time well spent.

—Claire Anderson, for the *Home Power* crew

Think About It...

"The secret of change is to focus all of your energy—
not on fighting the old, but on building the new."
—Socrates, Greek philosopher (470–399 BC)

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contributors

this issue's experts

Home Power Managing Editor **Claire Anderson** lives in a passive solar, (almost) net-zero-energy home she and her husband designed. She and her family are developing their 4.6-acre homestead to incorporate more resilience in their energy, food, and water systems. Chickens and ducks will be new additions this spring.

Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.

Jeff Tobe has been working in the solar industry since 2003 and currently works as a solar consultant on a variety of applications. With a focus on developing solar training and programs within indigenous communities, Jeff has recently completed several successful projects throughout the Southwest and Great Plains regions.

Author and educator **Dan Fink** has lived off the grid in the Northern Colorado mountains since 1991, 11 miles from the nearest power pole or phone line. He started installing off-grid systems in 1994, and is an IREC Certified Instructor for both PV and Small Wind. His company, Buckville Energy Consulting, is an accredited Continuing Education Provider for NABCEP, IREC, and ISPQ.

Katrin Klingenberg is cofounder and executive director of the Passive House Institute US (PHIUS). PHIUS promotes the wide adoption of passive building principles and standards in North America through specialized consultant training and certification, project and product certification, and educational efforts for building professionals and the general public.

Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who celebrated his 25th year of involvement with the magazine in 2015. He lives in an off-grid home in a redwood forest in Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.

Christopher Freitas is an engineer and project manager for international RE projects around the world. He was a cofounder of OutBack Power Systems and director of engineering at Trace Engineering, both located in Arlington, Washington.

Brian Mehalic is a NABCEP-certified PV professional, with experience designing, installing, servicing, and inspecting all types and sizes of PV systems. He also is a curriculum developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, lecturing, teaching, and consulting with homeowners.

Environmental writer **Juliet Grable** writes for regional and national publications on a wide range of topics, and currently serves as the managing editor for *Green Builder* magazine. Her background in natural history and ecology, and hands-on experience building a small, sustainable home inform her perspective. Juliet lives in southern Oregon.

Justine Sanchez is *Home Power*'s principal technical editor. She's held NABCEP PV installer certification and is certified by ISPQ as an Affiliated Master Trainer in Photovoltaics. An instructor with Solar Energy International since 1998, Justine leads PV Design courses and develops and updates curriculum. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

Zeke Yewdall is the chief PV engineer for Mile Hi Solar in Loveland, Colorado, and has had the opportunity to inspect and upgrade many of the first systems installed during Colorado's rebate program, which began in 2005. He also has upgraded many older off-grid systems. He teaches PV design classes for Solar Energy International.

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While reading *Home Power* is one of the best ways to get familiar with residential renewable energy, getting your hands on the tools and technology is the best way you can put these smarts into practice. Check out our Events & Education Directory at **homepower.com/events** for a class or workshop near you.

2015 Renewable Energy Fairs

When	What	Where	How
Mar. 20–22	Home, Garden & Green Living Show	Asheville, NC	southerngreenlivingexpo.com
Apr. 18	Douglas Co. Earth Day & Energy Fair	Roseburg, OR	bit.ly/DouglasFair
Jun. 19–21	The Energy Fair (aka MREF)	Custer, WI	midwestrenew.org
Jun. 26–27	Michigan Energy Fair	Mason, MI	glrea.org
Jun. 26–28	SolWest Renewable Energy Fair	La Grande, OR	solwest.org
July 25	NW SolarFest	Shoreline, WA	shorelinesolar.org
Aug. 16	Chena Hot Springs RE Fair	Chena, AK	chenahotsprings.com
Aug. 21–23	Crestone Energy Fair	Crestone, CO	scseed.org
Aug. 22–23	Illinois RE & Sustainable Lifestyle Fair	Oregon, IL	illinoisrenew.org
Sep. 12–13	Sustainable Living Fair	Fort Collins, CO	sustainablelivingassociation.org
Sep. 19	Clean Energy Fair	Missoula, MT	montanarenewables.org

For the Pros

Jun. 15–17	Small Wind Conference	Stevens Point, WI	smallwindconference.com
Jul. 13–16	Intersolar North America	San Francisco, CA	intersolar.us
Jul. 28–30	Solar 2015 (ASES)	State College, PA	ases.org
Sep. 14–17	Solar Power International	Anaheim, CA	www.solarpowerinternational.com

Courtesy Crown Battery

Crown Battery

2-Volt RE Batteries

Crown Battery (crownbattery.com) offers its CRP Power Module battery, designed for RE applications. Capacity options for these 2 V batteries range from 500 to 2,550 amp-hours (20-hour rate), more easily allowing a single battery string. Each battery has its own steel case with integrated handles for convenient handling. These batteries come with either threaded-stud or brass insert terminals, include a 10-year warranty (five-year free replacement; five-year prorated), and are manufactured in Fremont, Ohio.

Courtesy LG Solar

LG Solar

AC PV Module

LG Solar (bit.ly/LG-ACmodule) released its Mono X ACe 300-watt AC PV module. This module integrates a microinverter to eliminate DC cabling. Clips on the module frame allow AC cable management. The module's listed efficiency is 18.3%. Up to 12 modules can be in each 20-amp branch circuit (240 VAC). Module-level data is transmitted from the array via the AC output cable to the communications gateway, which is plugged into a 120 VAC outlet and Internet router for viewing with EnerVu software. (Note: Maximum static load for this module is specified at 50 pounds per square foot.)

—Justine Sanchez

Rainforest Connection

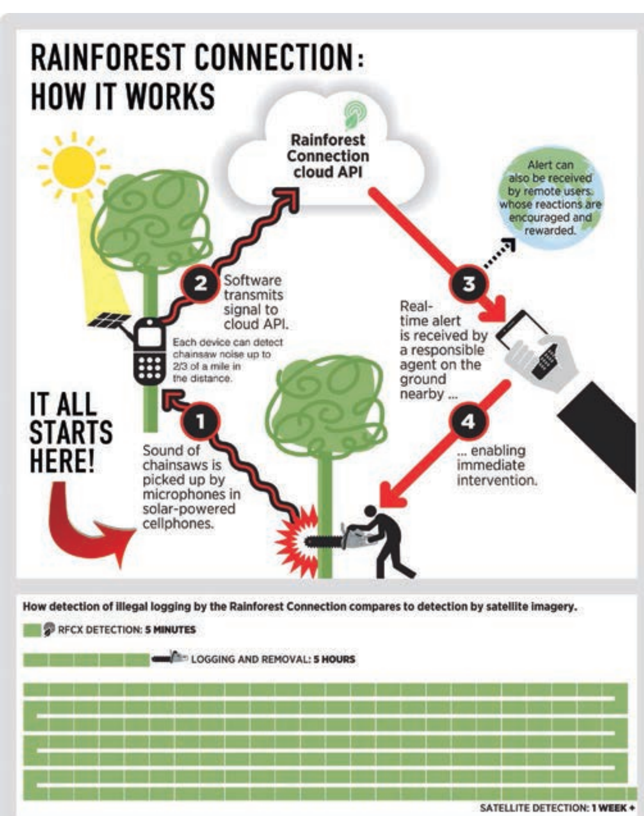
In 2011, software engineer Topher White traveled to Indonesia as a volunteer, where he visited a wildlife reserve focused on protecting gibbons, an endangered family of apes that inhabit rainforests in that region. Topher noted that the conservation organization was not able to control illegal logging, which threatened the forest, and therefore the gibbons. The forests are vast, and the small conservation organizations and authorities couldn't locate the illegal logging until after the damage was done.

Then inspiration for a solution dawned. Even though he was in a remote location, reliable wireless telecommunication was accessible, and cell phones were ubiquitous. If they could be used as remote sensors, he thought, detecting chainsaw and vehicle noises, and automated to alert local authorities, they could be used to protect the forest—and the gibbons.

When he returned to the states, Topher launched the nonprofit Rainforest Connection (RFCx; rfcx.org) to research and develop a prototype, which was completed in about six months. The "Guardian" detection device is a marriage of an Android phone; a powerful microphone; a 12 W PV array; an external lithium-ion battery; and a software application that senses noise and communicates the information via text messaging. The devices are installed in trees, and can detect sounds up to 1 kilometer away. They can distinguish chainsaw and vehicle noise from other forest sounds. The software may one day be further refined to identify animal distress calls and gunshots.

Courtesy RainforestCx

RFCx founder Topher White installs a demonstration/test prototype of the Guardian low on a tree during the development phase of the project.

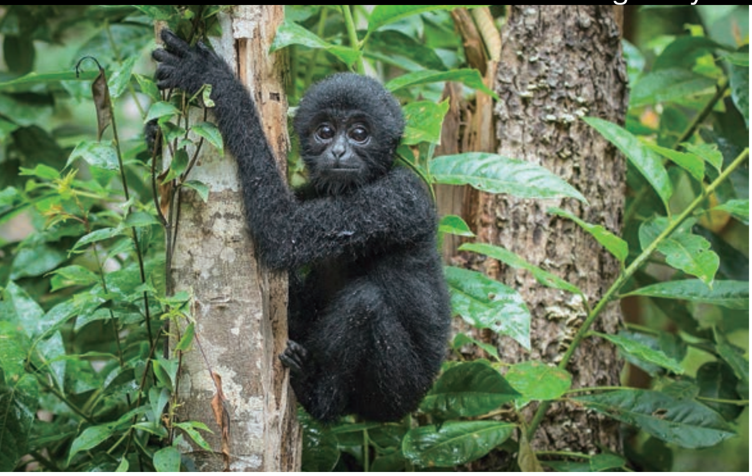


In the summer of 2013, the detection device was tested in the forests of Sumatra. The day after it was installed, it sensed the buzz of chainsaws and alerted the local NGO. They were able to arrive on the scene within minutes, effectively interrupting the loggers in the act. Based on this intervention, the recognition of the individuals involved, and subsequent follow-up by the local organization, there has been no more significant logging on their territory since.

A Kickstarter campaign in June 2014 brought the project wider attention and more funding. Four more devices were installed in Sumatra, and projects in Africa and Brazil are in process now. Topher and crew hope to continue to expand the program in various parts of the world, implementing it where the need is great.

Topher originally developed the app himself, and the open-source software has been refined by others on the team. The goal is that anyone could take their own phones and build devices around them. In the future, the devices may be used for catching poachers, tracking biodiversity, and more. By using overlapping devices, it's possible to triangulate and increase accuracy and therefore response success.

continued on page 18



Courtesy RainforestCx

Overview

Unit: Guardian

Array: "Flower" configuration; monocrystalline silicon; 1.5 V modules with voltage converter

Power Unit/Battery: External to phone, charged by PV modules; two parallel 3.7 V packs, lithium-ion, 8,800 mAh total

Days of Autonomy: 3–4

Power consumption: 0.4–0.7 W, depending on its mode of operation. Amount of energy consumed depends on the transmission time of a data packet

continued from page 16

For its current project installing devices in Cameroon, RFCx is partnering with the Zoological Society of London (zsl.org) and a local sustainable logging concession, SFID, in conjunction with about 50 in-country rangers. Topher's experience is that smaller, private organizations are more effective. "The larger and more monolithic an entity is, the more trouble it is getting it working on the ground." He insists on local people to manage and maintain the projects.

So far, interest in the devices has outstripped the organization's supply. To address this, RFCx has partnered with Sourcely, a recommerce company that is handling cellphone donations for the nonprofit. Using "upcycled" materials is part of RFCx's business ethic—D2 Solar supplied the last run of solar-electric cells, made from the offcuts of other solar projects on its production line.

—Ian Woofenden

get involved!

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Home-Built PV Racks

I have built a half dozen or so PV racks for our off-grid home and a neighbor's. One was a rack that was up 40 feet—in a tree; the other was our current rack, repurposed from a rock crusher, that pivots on a 7-inch tapered roller bearing. When faced with designing a rack for our new PV array, I again turned to the scrap-metal pile for inspiration. Long ago, I salvaged one of the large-diameter satellite TV dishes, and repurposed the welded aluminum framework as trusses. I had all of the steel to make the uprights, but had to purchase additional aluminum angle and channel. Still, I am at least $1,000 under the cost of a commercial rack, and I like the way it looks.

Steve Borgatti • via email

Courtesy Steve Borgatti

Creating custom racks can save some money, but the responsibility of making sure all of the appropriate engineering calculations have been considered and implemented falls on the system owner. For more information, see "The Right Fit" (homepower.com/161.44) and "Grid-Tied PV For $1.25 Per Watt" (homepower.com/164.38).

Justine Sanchez •
Home Power *technical editor*

Solar Water Pumping

I read Roy Butler's case study of a PV-powered water system to supply livestock water ("Methods" in *HP164*). The article got me thinking about the similar system (Grundfos direct PV pump, float switch, storage cistern, and gravity-pressure) that I built to supply domestic potable water for an off-grid residence. This full-time home for two is at 4,000 feet elevation in eastern Oregon, where summer temperatures can top 100°F and recent winter temperatures dropped to -20°F.

Our well installer used Grundfos sizing guides to supply a 6 SQF-2 pump powered by four 50-watt PV modules. This was to lift an average of 500 gallons per day 250 feet from the static water level (SWL) in the well to the cistern. I made a few different design choices for the remainder of the system that others might find interesting—or poorly considered.

The site has 132 feet of head above the house, allowing the water supply to be completely independent of the house's solar-electric system, and we didn't have to build or give up heated space for water pressurization (pressure tank and related plumbing). In the event of a failed pump, PV damage, or a fire emergency, the pump can be powered by AC.

The main water line passes close to the house, so the same pipe carries water up the hill and supplies the house. Use of a single main reduced the labor and pipe cost, and also allows water to be in motion more frequently—helping prevent freezing.

All supply pipe above the $1\frac{1}{4}$-inch well plumbing is 2-inch schedule 80 PVC, with brass valves at main control points. Using a large-diameter main limits friction loss and provides some resilience against mechanical and frost damage—we knew that a few segments would end up being shallowly buried due to rock. The valve layout allows the entire system—except for the well drop pipe—to be drained and for segments of the system to be isolated for cleaning or repair when needed.

The 3,000-gallon polyethylene cistern is bedded by sand on a cemented gravel subsoil at 2 feet. Half of the capacity is intended for routine use; half is reserved for fire protection and other emergency needs. The cistern has an overflow in case the float switch fails to operate properly. The supply main enters at the base of the tank (about 2 feet below grade), where freezing won't block water flow. This system was probably a bit costly and overbuilt from a conventional perspective, but we hope that it will be a lifetime capital investment.

Tyler Groo & Cheryl Ingersoll •
Paulina, Oregon

Kudos & Correction

Thanks for that awesome *HP164*. I think it was one of your best issues. My favorite articles are the DIY articles and the ones with the technical info on system sizing, performance, etc. Willi Hampel's article ("Grid-Tied PV for $1.25 Per Watt") hit the mark in all respects. Even if you don't want to tackle something that big yourself, this type of article provides an incredible understanding of what drives the system's design, cost, and performance.

The two articles on solar-powered water pumping were also great ("Solar-Powered Water Pumping" and "Methods"). Here in the southern Arizona desert, water is definitely a precious resource. These articles had it all—broad coverage of an interesting subject, great photo examples and diagrams, and "hands-on" sizing calculations that I find invaluable for illustrating how the systems work.

I have a minor correction on the solar water pump sizing calculation in the "Methods" department. I am a mechanical engineer and have done a lot of piping calculations over the years. Although it is true that only the height above the water level needs to be counted in the vertical head calculation, the full length of drop pipe should be included in the viscous pressure drop calculation.

In the example, the head loss of 2.93 per 100 feet should be multiplied by 170 feet, not 35 feet. In most cases, this distinction is small because the distance between water level and pump depth usually is not enough to make much difference. In this example, it only changes the answer by 4 feet of head; it would have a larger impact if the pipe was smaller or the flow rate was higher.

Thanks again for your very innovative and informative magazine.

Dan Gilb • Sahuarita, Arizona

Thanks for your feedback and the correction! You are absolutely right that the drop pipe must be included in the calculations. Many installations have drop pipe lengths measuring several hundred feet, and that would certainly add considerable friction loss to the system.

Roy Butler •
Four Winds Renewable Energy

Sun Tubes Lend Lighting Efficiency

I enjoyed reading the article on home lighting choices in *HP165* ("Efficient Home Lighting Choices" by Chris Calwell). I have a couple comments to add. First, we switched from CF to LED lighting primarily because modern CFLs take time to get to their full brightness. Most LED bulbs reach their full brightness almost instantly.

One of the best ways we found to reduce lighting costs during the day is by using natural light. We are particularly happy with our tubular skylights that we installed in our kitchen and bathroom. Before they were in place, we needed to turn the lights on during the day to get sufficient illumination.

Courtesy Jack Herndon (2)

I installed two 10-inch tubes in the kitchen and an 8-inch one in the bathroom. It was as if we added a couple of 100-watt downlights in the kitchen. Even on cloudy days, we rarely use artificial lighting.

Solar tubes have very low thermal transmission. And when properly installed, they do not allow air infiltration. They are easy to DIY on composite roofs.

Jack Herndon • Seattle, Washington

EV Payback

In *HP165*, Brad Berman offers practical guidance for the purist in all of us—how to put clean energy in your travel future, regardless of your local utility's fossil power content ("Fueling with Sunshine"). He offers a nice example of the positive cash flow that can result under time-of-use (TOU) billing, when a PV system is generating surplus energy during peak hours and an EV is recharged during nonpeak hours.

We should consider that, in the history of cars, no one has ever expected cars to yield payback. The cost of fuel is just the cost of your mobility independence. So why is this often included in an EV's economic evaluation? Try looking at it this way: Add the savings from your now-zeroed gasoline card account to the net positive income from PV generation, and you have a substantial credit every year. Then compute PV payback from this accumulating annual total. If it's five years, your PV investment yields 20%—with no risk. You can't possibly get this return on any other risk-free investment. The key is, you get to set your own accounting rules. Leave EV payback out of it. Cars don't pay for themselves, but clean energy does.

Tracy Farwell • Portland, Oregon

write to:

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Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

"Dry" Lead-Acid Batteries

I have a batteryless grid-tied PV system that is working well, but would like to have some backup electricity if the grid goes down long-term. I understand that one straightforward solution is to buy an inverter that will work in an AC-coupled and/or completely off-grid mode. But rewiring the modules for this configuration would cost several thousand dollars for the equipment and labor.

Another option would be to buy a battery bank and inverter to create an uninterruptible power supply (UPS). In the event of a grid failure, the UPS would provide some electricity for critical loads, but leave me with a roof covered with untapped PV modules.

Perhaps my money would be best spent on equipment that I could use to morph my system into an off-grid one. I could rewire my PV modules without optimizers or any controls. I could buy an inexpensive pulse-width-modulated charge controller, a battery-based inverter, and a bunch of batteries, and put it all in storage for the day there is a prolonged outage. I understand that storing wet lead-acid batteries is a bad idea, but what about storing *dry* batteries? They are all sold as wet, but I've heard that you can drain and rinse them, and then store them for a long time. I can store sulfuric acid in a bottle with no degradation, but what about the empty battery?

Wayne Johnson • via homepower.com

The most cost-effective backup solution for folks who experience infrequent grid blackouts is usually a fossil-fuel generator and transfer switch, whether grid-tied PV is installed or not. But if you are prepping for a more prolonged grid outage, fossil-fuel storage and availability could quickly become a problem.

Nickel-iron batteries are an old technology experiencing a renaissance. They trade a little bit of efficiency for long-term stability.

Courtesy Iron Edison Battery Co.

Your logic in avoiding commissioning an expensive backup battery bank only to have it deteriorate over just a few years even with very little use is very sound. Unfortunately, the chemistry of lead-acid batteries starts working against you the moment the battery plates are electrochemically "formed" at the factory. "Dry-charged" lead-acid batteries would be better called "moist-charged." After the battery is manufactured, the electrolyte is drained and the batteries shipped to distributors. The distributors then mix up new electrolyte, refill the batteries, and re-activate them using a slow, carefully prescribed and monitored charging regime. This lets them avoid expensive shipping

charges for hazardous materials, and gives the battery extra shelf life—about eight to 18 months. The longer the moist-charge storage period, the longer it takes to reactivate them, and some damage occurs from the moment the battery leaves the factory.

If you're considering storing batteries, consider nickel-iron (NiFe) chemistry (also called "Edison cells"). These batteries are regaining popularity because of their long life and resistance to abuses that could kill a typical flooded lead-acid battery very quickly. NiFe cells can be discharged to a much lower state of charge (SOC) regularly without damage, and can be mothballed for years with little or no deterioration, leaving the electrolyte in. Even after prolonged storage, a few charge/discharge cycles will revive a NiFe battery to normal operation, as long as the electrolyte has always been kept at recommended levels.

NiFe batteries have some disadvantages—higher cost, lower energy density per weight, less efficient charging and discharging, and a higher self-discharge rate. But these issues are not serious for a stationary, off-grid home installation. Some modern charge controllers and inverter/chargers now have pre-programmed settings for NiFe cells that will keep them healthy for decades. Be sure to carefully follow the battery manufacturer's instructions for controller settings; clean and tighten battery connections regularly; and always keep the electrolyte topped off—just like you should do for any battery technology.

All batteries are a form of electrochemical "controlled corrosion" that can be harnessed for storing and releasing energy. The trick is choosing the right battery technology and sizing the system for your particular situation.

Dan Fink • Buckville Energy

Batteries & Temperature

In Zeke Yewdall's article on MPPT charge controllers (*HP162*) he says, "When a battery is cold, its internal resistance increases, which causes the voltage to rise (assuming a constant current)..."

I'm confused. My gut says, as temperature increases, resistance increases. I understand voltage is inversely proportional to temperature, but I didn't think resistance went down with temperature. Can you explain this?

Loren Dickey • Orcas Island, Washington

The answer is that batteries have a complex chemical reaction, and do not share the same heat-related characteristics as simple copper wire. When discharging a typical lead-acid battery, lead combines with negatively charged sulfuric acid ions at the negative plate, producing lead sulfate and two extra electrons, which flow through the battery cables and load to the positive plate, where lead oxide combines with sulfuric acid and electrons to create lead sulfate and water. A charged battery contains lead and lead oxide plates, with sulfuric acid as the electrolyte—a totally discharged battery just contains water as the electrolyte, with lead sulfate-coated plates. If it remains discharged for too long, the sulfate crystallizes and may not release from the plates, a condition known as sulfation. Because it has weaker and weaker acid (more water, less acid) as it discharges, it also is more susceptible to freezing.

You are right that wire resistance decreases at colder temperatures. However, "resistance" in a battery is different. At a given temperature and voltage, the chemical reaction in a battery can only proceed at a certain rate. If we try to pull more energy from the battery at a low temperature, the chemical process can't keep up, and the battery voltage drops because it can't provide enough electrons.

To provide each electron requires a chemical reaction, and the speed of the chemical reaction depends on the mobility of all the chemicals in the electrolyte. A new sulfuric acid ion needs to move next to the lead or lead oxide plate to take place in the next reaction, and the water molecules need to move away from the positive lead-oxide plate. At higher temperatures, Brownian motion of the molecules make them diffuse back and forth faster, and new molecules come into contact with the plates faster.

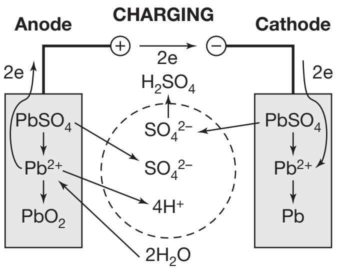
More plate area also helps the reaction. This is why automotive starting batteries have many thin plates compared to the fewer thick plates found in deep-cycle batteries. Even in cold conditions, enough molecules are available to touch enough plates. Having many thin plates makes them a lot more fragile, so they cannot mechanically survive being switched from lead to lead sulfate as many times. Deep cycling is worse for batteries with thin plates than for thick, even though they work better in cold weather.

The result is that voltage drops more when you try to pull energy from a cold battery than a warm battery; this is described as higher internal resistance. But it's not resistance in the electrical sense of electrons having trouble getting through a piece of metal; it's actually more difficulty in generating the electrons to begin with.

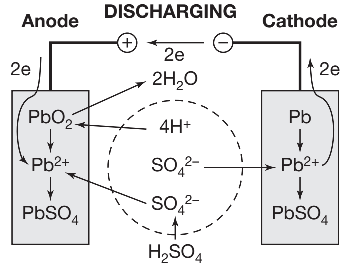
Similarly, when we try to charge a cold battery, we are trying to push more electrons in there than can actively take place in the chemical reaction, because one completed molecule has to move out of the way before the next one can accept an electron. So then, we see that the voltage is higher for the cold battery than the voltage for the warm battery would be. Again, this is because the cold chemical reactions are limiting how fast the battery can absorb electrons, not because of an actual increase in electrical resistance.

Zeke Yewdall • Ward, Colorado

Battery Charge & Discharge Chemical Reactions



Charging: Lead oxide is formed at the anode; pure lead is formed at the cathode. Sulfate ions are liberated into the electrolyte, causing the specific gravity to increase.



Discharging: Lead sulfate is formed at both electrodes. Sulfate ions are removed from the electrolyte, causing the specific gravity to decrease.

A charge controller with an auxiliary output option can control a relay, such as the one shown here, to send energy to loads when the batteries are full.

Ian Woofenden

Solar EV Diversion

Where I live, gasoline (brought to our small island) costs $7 per gallon, so I'm considering buying an electric vehicle (EV) that I can charge from my off-grid PV system. When the batteries are in float charge, is there a way that I can automatically divert surplus solar electricity from the PV system to charge an EV automatically? I have an OutBack inverter and controller, with a remote monitor in my home that helps keep tabs on the system.

Bill Appel • via e-mail

Taking advantage of your excess solar energy to charge an EV makes great sense. The easiest way to make the connection between your solar-electric system and the electric vehicle is via AC power, since this allows use of the vehicle's existing battery charger. Because you already have both a charge controller and inverter that can control an external relay, the connection will be fairly simple.

The OutBack charge controller's auxiliary output should be connected to a relay with a 12 VDC coil that draws less than 0.2 amps—these are fairly easy to find. The relay's contacts need to be rated for at least 15 amps AC (check your EV charger's requirements). The controller's aux output needs to be programmed to activate the relay when the battery gets close to being full. The best aux output mode to use for your application is probably the "Diversion: Relay" mode, which will automatically activate the relay at a programmed voltage below the controller's float/absorb/equalization setting, and takes into account the battery's temperature.

I advise powering the charger only with 120 VAC—even if your solar-electric system and vehicle battery charger have 240 VAC capability. The amount of power required when charging at 120 VAC is much lower and probably a better match to the surplus electricity available from your PV array.

Some tuning and experimentation will be required to find the best match between your solar array, system battery, and battery charger. On the OutBack controller, both the voltage hysteresis (difference between when it turns the relay on and off) and a time delay and minimum "on" time period can be adjusted to reduce rapid cycling. The settings depend on the size of your PV array, system voltage, charger power consumption, etc., so I can't suggest specific settings.

Christopher Freitas • SunEPI

write to:

asktheexperts@homepower.com

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Modern Small & Solar

by Juliet Grable

As retirement drew near, it seemed only fitting that the capstone for homebuilder Steve Asher's 25-plus-year career would showcase his construction and design skills. What was unexpected was that he'd fit it in less than 840 square feet.

All photos by Ben Root unless noted

Above: A greenhouse and sauna flank the north side of the courtyard, which includes a fire pit for chilly nights.

Left: A shower on the house's exterior offers a place to rinse off after outdoor chores.

Steve Asher and his wife Buffie were living in a 3,000-square-foot home near Ashland, Oregon, when he completed the initial design for their "Trophy House"—and then started to reconsider.

Even though he planned to cover the rooftop with PV modules, "It was [still] a 3,000-square-foot, million-dollar home," says Steve.

And Buffie chafed against the idea of another large house. "I was just tired of always cleaning," she says. "I thought, I'd rather live anywhere I don't have to do this every day. I could never really relax."

He did not really want a future of taking on jobs just to offset the costs of owning and maintaining a large home. Another factor influenced their decision to downsize. When

The west wall of the courtyard is bermed into the steep hillside, giving the enclave a cozy feel, even with the expansive east view.

The custom kitchen island converts to a dining table, with knee room all around, by rolling away the kitchen-side lower cabinets.

The streamlined kitchen offers modern conveniences in a small footprint.

Creative design and careful use of space make the small footprint highly functional, while feeling comfortable and inviting.

the sale of their house fell through, they decided to rent it out instead, and moved into the "rec room"—an 864-square-foot space where Steve's kids used to hang out. It was a makeshift situation: no kitchen, no large house to clean. And Buffie loved it.

"It was like pseudo-camping," she says. "The chores were different, and everything was temporary." This experience convinced them that downsizing could free up a precious resource: their time. So Steve went back to the drawing board on a second, more modest design.

The sleeping nook was originally designed to have drapery separating it from the main living area, but the Ashers find they seldom need the privacy and appreciate the natural light and openness.

The eastern-facing main entrance, which is mostly glass, allows ample morning light and some passive heat to enter. During warmer weather, the doors can be swung wide open to naturally ventilate the house.

Searching for Solar

Steve has designed and built net-zero energy homes for several clients; he's a building science expert and runs a green building consulting service on the side. Coming out of the recession, he was determined to make self-sufficiency a priority for his own family. "We wanted to [function as if] off-grid, but still be grid-tied," says Steve.

Although he owned 5 acres near Ashland, the site—with its steep, forested, east-facing slope—wasn't perfectly suited for solar. The couple started searching for property with ideal southern exposure. They even visited Michael Reynolds' Earthships in Arizona, and briefly considered moving there.

But the recession convinced them to work with what they already had—land that was paid for, even if it lacked perfect solar access. They decided they couldn't even build the smaller redesigned house without borrowing from a bank. They could, however, afford to build the planned "garage"—which Steve had originally intended to use as a shop and office—and several smaller outbuildings.

A perfect puzzle: Steve designed the mechanical systems to fit into otherwise wasted spaces. The HRV sits in a bathroom cabinet, and the water heater hides behind another rollaway unit.

"At that point, the fun began," says Steve. The design for the garage-cum-studio soon morphed into "a statement and model—an adventure in living." The result is a small compound designed around a courtyard. The studio flanks the south end and measures 840 square feet; its northwest side is bermed into the hillside. Across the courtyard is a sauna, a small greenhouse, and a storage room, which are all connected. Pear trees and raised garden beds surround the courtyard, which includes a patio, outdoor kitchen, and outdoor shower. "We live outside six months out of the year," says Steve. "This design reflects our lifestyle."

Innovation for Small Spaces

Steve was a veteran at designing small spaces, having built some of the first accessory dwelling units (ADUs) in Ashland nearly 15 years ago, when the town started encouraging infill building to take advantage of existing infrastructure and discourage urban sprawl. "ADUs are the ultimate design challenge," he says. "How do you take a 400- to 500-square-foot rectangle and make it livable?" His experience with ADUs informed the studio's design. The shop space became living room/kitchen; the office became the bedroom. Although the floor plan is open, the roof's butterfly design—two gables that slope inward to form a central valley—provides a visual separation between the sleeping area and the rest of the house.

"The real trick was getting everything to fit," says Steve. The kitchen includes an island with cabinets on casters; moving the cabinets transforms the island into a dining table. Built-ins line the walls in both the sleeping and living areas. A cabinet accommodates the heat-recovery ventilator. A corner cabinet in the bathroom, set on casters, hides a 40-gallon electric tank water heater, and can be pulled out when the unit needs servicing.

The sloped site and surrounding woods preclude much southern solar access. Instead, the main view, solar exposure, and building orientation is easterly. For this reason, the roof wasn't ideal for a solar array either, but allowed the creative butterfly design.

Capturing Solar, Detailing Efficiency

When he was siting the house, Steve consulted his books on passive solar design. According to his calculations, the orientation—a fairly steep east-facing slope with some southern exposure—was less than optimal for trying to heat the space solely with passive solar gain. However, the calculations didn't take into account the waste heat generated by appliances and the occupants. The small studio functions much like a Passive House, reducing heating energy demand with a supertight envelope. Most of the glazing is loaded into the front, southeast façade.

The foundation is a 5-inch concrete slab poured over 4 inches of XPS rigid-foam insulation for R-20. The slab and foundation are thermally isolated with 2 inches of R-10 rigid foam, an important detail. The earth-bermed portions of the exterior concrete walls are insulated with R-10 rigid foam.

Double-wall construction—a 2-by-6 exterior stud wall with a 2-by-4 wall inside, separated by a 3-inch gap—resulted in a 12-inch-thick wall space with no thermal bridging. Four inches of closed-cell Demilec Heatlok (part soy-based oil and recycled plastic bottles) and 8 inches of open-cell Demilec Sealection Agribalance result in an average insulation value of R-50.

The roof framing is 2-by-8 ceiling joists sheathed with 5/8-inch plywood, suspended from glu-lam beams. Two-by-four rafters run perpendicular and on top of the first assembly, and are also sheathed in plywood. This system provides superior air-sealing—the can lights, for instance, are contained completely within the first assembly. It also reduces thermal bridging where the two assemblies intersect. The ceiling is R-60 and includes 5 inches of open-cell insulation, 3 inches of closed-cell insulation, and 3.5 inches of rigid foam in the rafters.

Inside, open- and closed-cell spray foams were used in wall and ceiling cavities, providing a vapor barrier and superior insulation.

Courtesy Buffie Asher (2)

Above the main roof sheathing, another set of rafters provided space for rigid foam board, bringing the roof insulation to R-60.

The result is an airtight house that minimizes heat flow through its envelope. The house performs comparably to a Passive House—a blower door test came in at 0.8 air changes per hour (ACH).

"I tell people my house is like a battery," says Steve. In the winter, good air-sealing and high levels of insulation help hold in the heat, while thermal mass in the concrete floor absorbs, stores, and reradiates it. One firing of their EPA-certified Avalon Camano wood heater covers four to five days, even during cold snaps. Five-eighths-inch DensShield—a high-density paperless drywall usually used as tile backing—sheathes the interior. Steve believes that the denser wallboard adds to the home's overall thermal mass.

"I think using this [instead of conventional drywall] is the wave of the future," says Steve. But he wanted to see how the harder and heavier wallboard was going to be for the hangers. Steve also used a liquid, spray-applied polymer-modified asphalt coating under the exterior stucco—EnviroDri by Canada-based Tremco—for the home's weather-resistant barrier.

Two skylights, along with many windows and full-light glass doors, admit ample natural light and create a feeling of spaciousness inside the studio. The Ashers installed Sierra Pacific double-pane low-e patio doors with a 0.32 U-factor, and chose double-pane, low-e vinyl Milgard windows with a 0.28 U-factor.

"I didn't spend extra money on windows, and I'm so glad I didn't," says Steve. He estimates that purchasing triple-pane windows would have tacked on $10,000 to the home's costs. The solar gain admitted by the windows helps warm the space in winter, and so far, summer overheating hasn't been an issue.

The small Avalon Camano wood heater provides enough heat from one firing to keep the superinsulated home warm for up to five days.

Fire & Water

Southern Oregon summers are synonymous with fire season. For the house, fire protection drove many exterior material choices—like the stucco siding, metal roofing, and steel posts and beams. The soffits are finished with stucco, and the fascia are Kynar-finished steel.

The elaborate water system includes four storage tanks. The pump house sits near the studio on top of a 2,000-gallon concrete storage tank.

Two 235-watt PV modules power a Grundfos pump, sized for the 100-foot lift from the well to two 1,700-gallon fiberglass tanks located on the slope above the studio. From there, water is gravity-fed to a potable-water tank at the house and a second concrete tank near the garden. The second tank also serves as the foundation for the garden shed. Steve has plumbed hoses with fire-suppression nozzles at several locations.

"The water system is very important," says Steve. "Besides fire protection, we want to be prepared if the climate changes, and trees aren't getting the water they need." These include the many deciduous trees and conifers—firs, pines, cedars, redwoods, maples, and dogwood—Steve has planted throughout his acreage.

The 470-watt PV array on the pump house powers DC pumps that convey water to storage tanks, which provide water for irrigation and fire suppression needs.

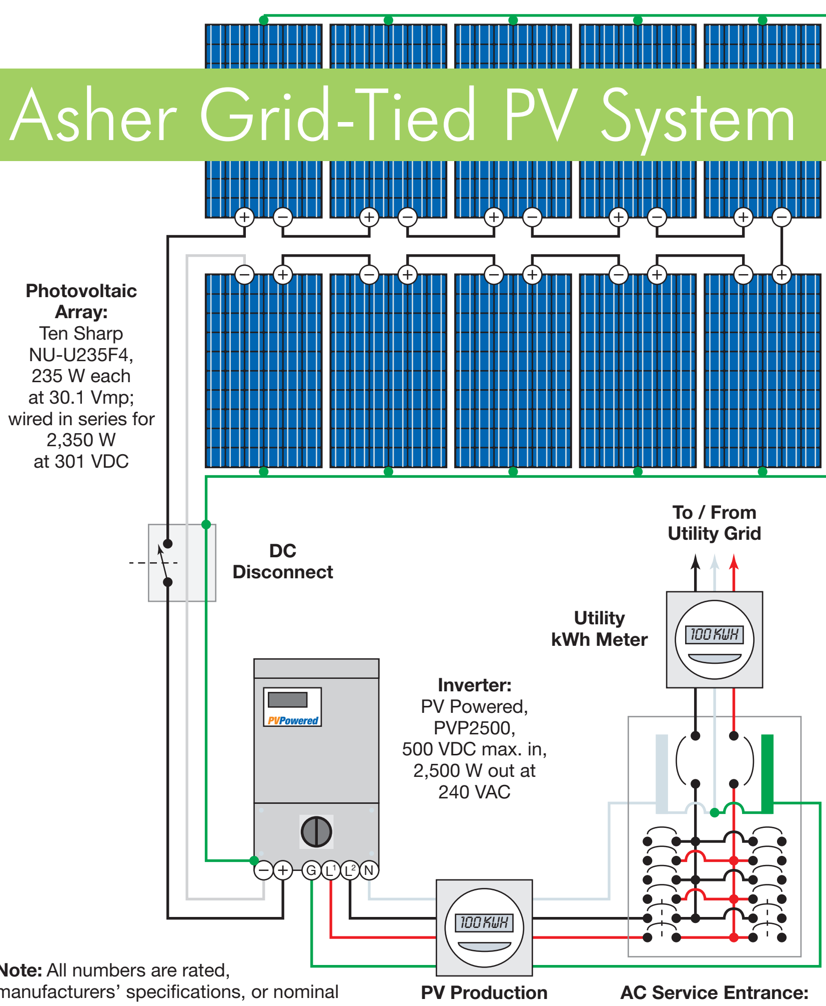
Mechanical Efficiency

A Venmar Kubix heat recovery ventilator (HRV) ensures good ventilation, but the Ashers also vent naturally by opening windows and doors. All of the home's appliances are electric. A Daikin Electric ductless minisplit heat pump provides backup heating and cooling. Low-flow water fixtures, all-LED lighting (including Cree LED can lights), and Energy Star appliances help make this house an energy- and water-miser.

Above: A PV Powered 2,500-watt inverter, production meter, and disconnect (not shown) round out the balance-of-system components for this grid-tied installation.

Ten 235-watt Sharp PV modules on the roof of the garden shed provide 65% of the Ashers' energy needs.

Asher Grid-Tied PV System



Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

Tech Specs

Overview

Project name: Asher residence

System type: Batteryless grid-tied solar-electric

Installer: Alternative Energy Systems

Date commissioned: January 2012

Location: Ashland, Oregon

Latitude: 42.37°

Solar resource (average daily sun-hours): 4.9

ASHRAE lowest expected ambient temperature: 17.6 °F

Average summer high temperature: 96.8°F

Average monthly production: 196 kWh

Annual utility electricity offset: 65%

PV System Components

Modules: 10 Sharp NU-U235F4, 235 W, Vmp 30.1 V, Imp 7.81 A, Voc 37.0 V, Isc 8.50 A

Array: 2,350 W STC total

Array Installation: SnapNrack Series 100 mounts installed parallel to roof on south-facing roof (garden shed: 30° tilt)

Inverter: PV Powered PVP2500; 500 VDC maximum input voltage; 140–450 VDC operating range; 240 VAC output

Asher System Costs

Item	Amount
System price	$11,750
Federal tax credit	-2,466
Oregon tax credit	-4,935
Energy Trust of Oregon rebate	-3,525
Final Cost	$824

Future plans are to install more PV modules on the garage roof to achieve net-zero energy use on an annual basis.

The Ashers are taking a gradual approaching to reaching net-zero energy. Their 2.35 kW batteryless grid-tied PV array, on a garden shed roof about 100 feet below the studio, offsets about 65% of their electricity usage. The butterfly roof on the studio wasn't ideal for PV—they plan to install another array on the detached garage that sits on the north end of the compound, with the eventual goal of reaching net-zero or net-positive.

Steve hopes to use his house as a blueprint for others. Its small footprint and simple but efficient design could be adapted to other sites very affordably. He and Buffie also want to show others that living small can mean a superior quality of life.

Their house was one of five on the 2014 Rogue Valley Green and Solar Tour, and Steve gave a presentation about the home at a Green Drinks event earlier that year. He has also talked about putting together a practical "how-to" guide for building a super-small, energy-efficient home.

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PV Racks with Integrated Equipment Grounding

by Justine Sanchez

Innovations in PV module rack systems offer more streamlined, straightforward installation, reducing materials and labor.

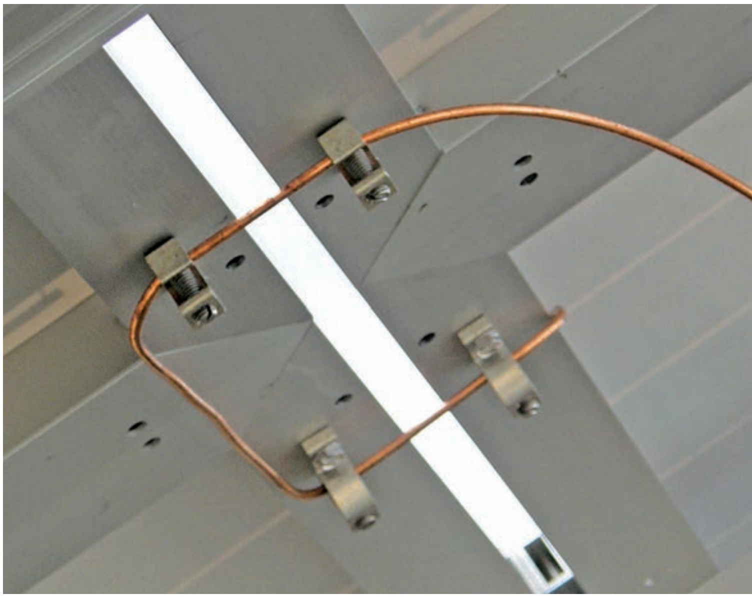
Courtesy Quick Mount PV

Above: Where's the ground wire? Module frames and racks, electrically bonded by piercing clips, become the EGC network.

Below: Traditionally, lay-in lugs attached to module frames held a continuous copper wire acting as EGC. This method was parts- and labor-intensive.

It seems that each year the photovoltaic (PV) industry makes strides to become more cost-competitive with conventional power sources. From simpler module wiring to combining functions within inverters, equipment manufacturers have found ways to reduce material use (and thus cost). With multiple functions in one piece of equipment, an added benefit is streamlined installation. Module rack systems have likewise evolved, with the result of decreasing installation time. One of the most notable recent innovations in racking is "integrated grounding (IG)," now offered by several rack manufacturers.

To understand what integrated grounding is—and why it is getting much attention in the industry—you need to understand how time-consuming and detailed the grounding process once was. In the past, an equipment-grounding conductor (EGC) was secured to each module by a lay-in lug. This was attached to the module grounding point with a stainless steel thread-forming screw—after the surface was properly prepared by sanding off the module frame anodization at the point of lug contact. The grounding wire continued in this way from module to module, then to another lay-in lug bonded to the rack, then to any other metallic electrical box, and so on—to connect to the rest of the equipment grounding system (see "Code Corner" in *HP102*).



Courtesy AEE Solar

Top-Down Shows Up

Soon, "top-down" module mounting—with two rails under each row of modules and the modules secured to the rails by clips accessible from above the modules—became commonplace. End-clips are used to secure modules at the end of each row, and mid-clips are used between adjacent modules. The clips are bolted to the rail; their edges overlap the module frames to secure the module against the rails. Bonding washers placed between the module frame and the rail replaced the lay-in lug and wire. When the clips are tightened, the teeth of the washer pierce both the module frame and the rail to electrically connect the rack and modules.

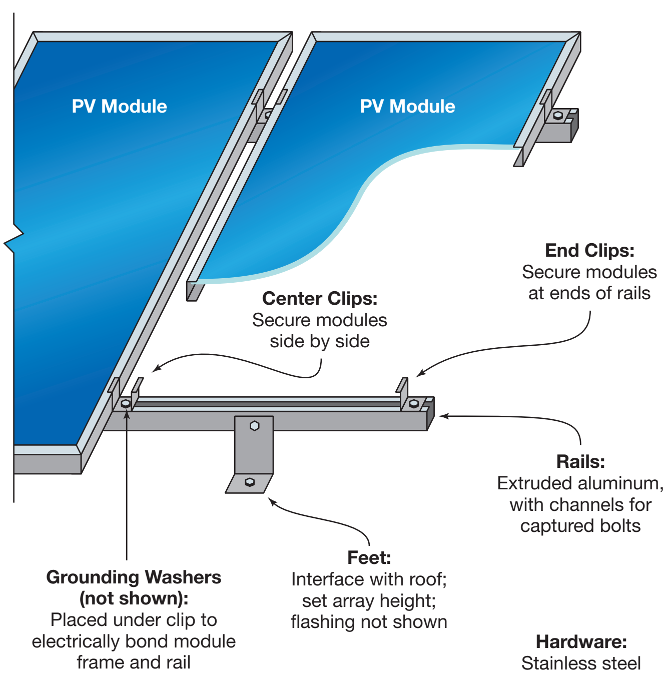
This method sped up the equipment-grounding process since no surface preparation is required. It also reduced expense—the bonding washers are less expensive than lay-in lugs and the EGC that had to span all the module frames (see "Code Corner" in *HP152*.)

Equipment Grounding

The *National Electrical Code (NEC)* defines the electrical term "ground" as "the earth." Grounded (grounding) is defined as "connected (connecting) to ground or to a conductive body that extends the ground connection."

All electrical systems require equipment grounding—the practice of connecting all metallic enclosures, module frames, conduit, and racks (i.e., all metallic objects in an electrical system) with an equipment-grounding conductor (EGC). This EGC must be connected to the rest of the grounding system, which includes an electrical path back to a grounding electrode (commonly a ground rod) that has a direct connection with (i.e., is buried in) the earth. Equipment grounding is a safety measure to reduce shock hazards. Should a ground fault—unintentional electricity flowing, for example, in a module frame due to a nicked wire—occur, the electricity has an alternate (and low-resistance) pathway to the earth, rather than through a human.

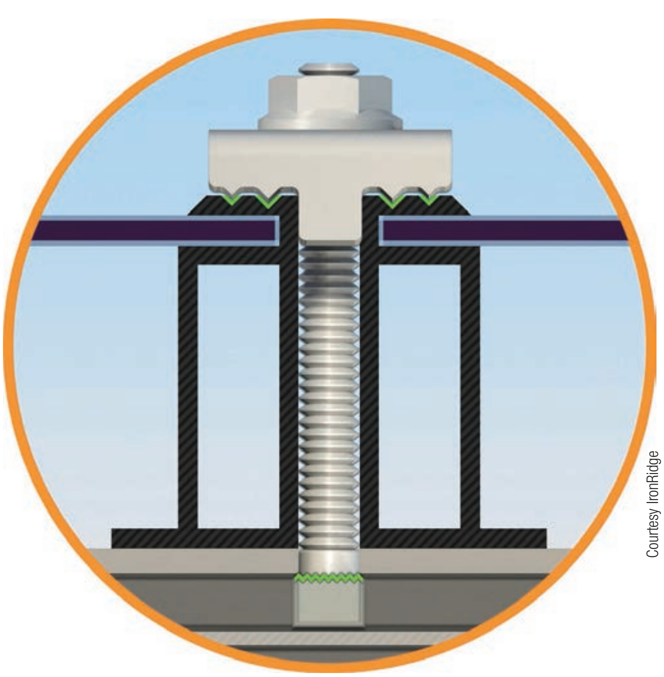
Top-Down Racking with Bonding Washers



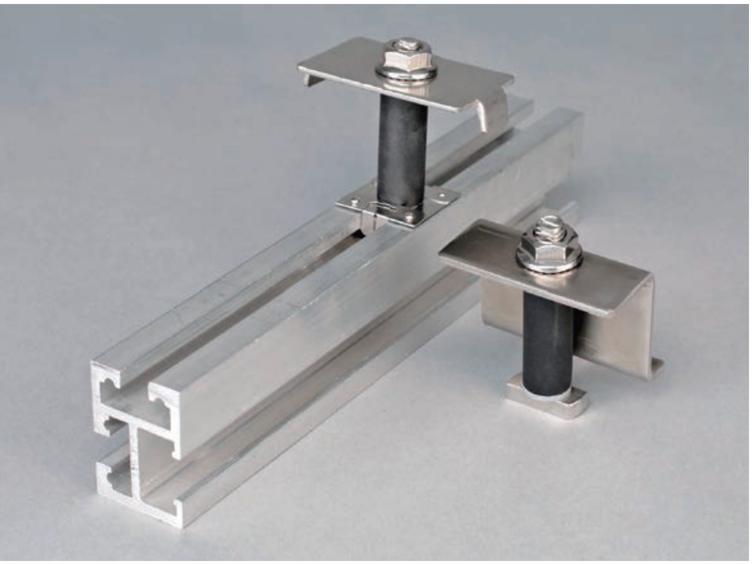
Bonding washers, like this Wiley (Burndy) WEEB, cut into metal module frames and rack rails to make electrical contact. A variety of styles fit specific rack designs.

On to Integration—With or Without Rails

The logical next step in top-down mounting and module grounding is bonding clips that, when bolted down, simultaneously secure the module to the rail, and electrically bond adjacent modules and the underlying rail. It eliminates the need for separate bonding hardware (bonding washers or lay-in lugs). While bonding clips vary in shape and dimensions, all have a method—usually sharp, serrated surfaces—to pierce the frames' and rails' anodized coating when the clip is secured.



The IronRidge module clamp has cutting teeth that make electrical connections (shown in green) at both the module frame and rail.

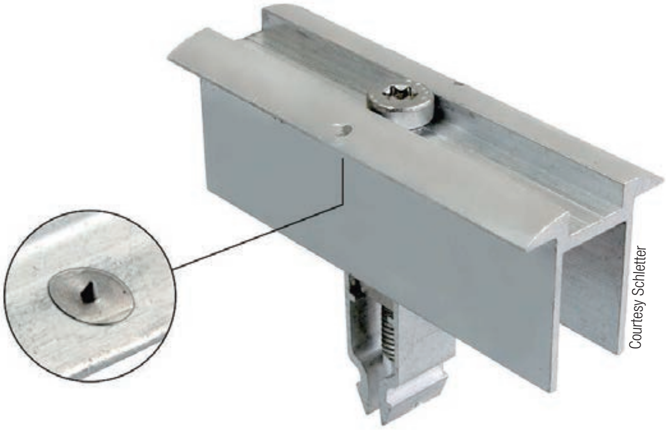


Courtesy Direct Power & Water

DP&W offers midclamps with WEEB piercing clips to create the grounding bond to module frame and rail.

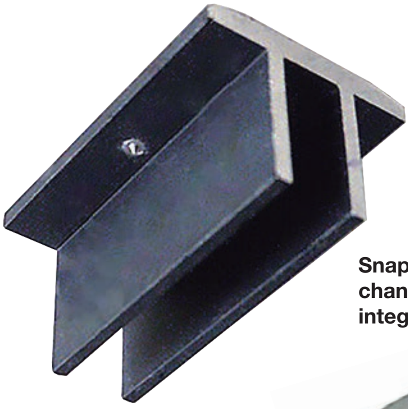
Courtesy IronRidge

The IronRidge hardware shows piercing teeth (on the top clamp) and the captive bolt head (at the bottom).



Courtesy Schletter

The Schletter midclamp has points under the lip to pierce the module frames.



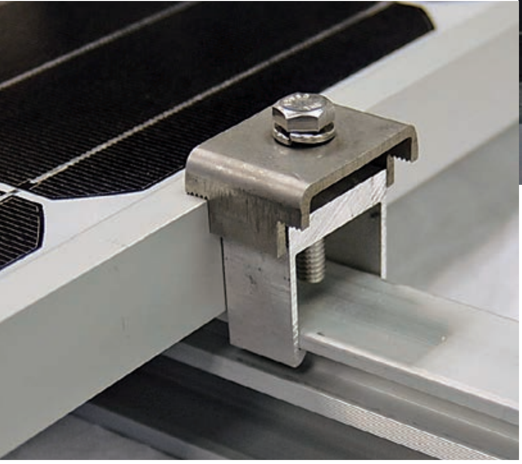
SnapNrack's top clamp and channel nut both have sharp integrated bonding points.

Courtesy SnapNrack

Courtesy Solar SpeedRack

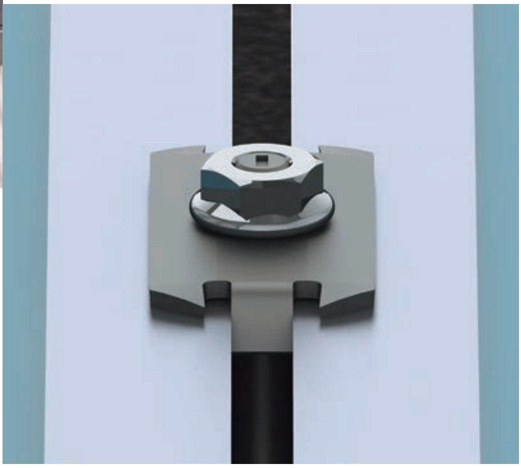
Above: Solar SpeedRack's mounting rails have pre-installed grounding springs that bite into module frames and rails when the module is placed into the rail rack.

Magerack's midclamp also has module-frame-piercing teeth.



Courtesy Magerack

Unirac's bonding midclamp assembly pierces the anodized finish on the module frames to electrically bond modules together.



Courtesy Unirac

Integrated grounding is still an innovation, so at this time, each manufacturer typically offers only one rack system with this feature—note the specific rack model(s) in the "Integrated Grounding" table (and don't assume that all of the other products the manufacturer makes have IG capability).

Using IG rack systems requires paying attention to a couple of important details. One is when the length of the array requires multiple sections of rail. If that's the case, these sections of rail must be spliced together. Some IG rack systems provide rail-splicing hardware to electrically bond the rail sections; others may require specific grounding straps—in addition to the splicing hardware—between sections of rail to ensure electrical continuity.

Courtesy SnapNrack

SnapNrack's bonding rail couplers join the rails mechanically and electrically.

IronRidge's braided ground strap, which electrically bonds adjacent lengths of rail.

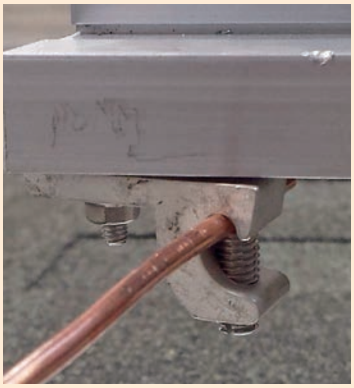
Courtesy IronRidge

Some manufacturers' IG systems use bonding end-clips, while others only use bonding mid-clips, which bond adjacent module frames. This distinction becomes particularly important in the event that a module adjacent to an end module needs to be removed. If the system uses only bonding mid-clips, removing that module will interrupt the equipment grounding system, leaving that last module frame ungrounded. In this case, a temporary bonding connection must be made to ensure grounding of that end module.

Homerun EGC

Even with integrated grounding, an EGC still needs to be bonded to the array installation. This is commonly accomplished with only a single bonding connection, such as a lay-in lug, and connects the array to the rest of the grounding system. This grounding connection point is much easier and faster to install than separately grounding each module with its own bonding hardware.

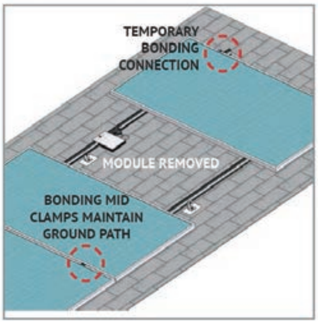
For extra safety, some installers go beyond the minimum requirement of having a single EGC attachment point. Multiple EGC attachments ensure that the entire array EGC pathway back to the rest of the grounding system isn't dependent on a single point of contact.



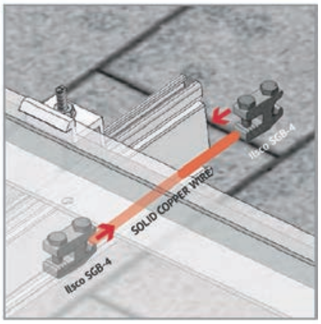
Commonly, only a single ground wire connection is required for an array that has integrated grounding.

Courtesy Spider-Rax

Example of Creating a Temporary Bonding Connection During Array Maintenance



When removing modules for replacement or system maintenance, any module left in place that is secured with a bonding midclamp will be properly grounded. If a module adjacent to the end module of a row is removed, or if any other maintenance condition leaves a module without a bonding midclamp (and there are no bonding end-clamps), a temporary bonding connection must be installed.



Courtesy Unirac (2)

PV Racks with Integrated Grounding

Manufacturer	Roof or Ground Mount	Integrated Grounding Rack Models	Railless	Bonding End-Clamp	Grounding Straps Required Between Rails	UL Listing	Modules Noted in Mfr and/or NRTL documentation
Direct Power & Water dpwsolar.com	Roof	Power Rail Mounting with integrated WEEB	No	No	Yes	467	N/A
IronRidge ironridge.com	Roof	Roof Mount System	No	No	Yes	2703	Module dimensions range specified
Magerack magerack.com	Roof	Magerack Mounting System	No	Yes	Grounding built into splices	2703	Kyocera modules evaluated
PMC Industries pmcind.com	Roof: Standing seam metal	ACE Clamp	Yes	N/A	N/A	2703	LDK & CNPV modules evaluated
Quick Mount PV quickmountpv.com	Roof	Quick Rack	Yes	N/A	N/A	2703	Many, see documentation
S-5! s-5.com	Roof: Standing seam metal only	S-5-PV Kit	Yes	N/A	N/A	2703	Module dimensions range specified
Schletter schletter.us	Both	Flush (roof) & FS Kit (ground)	No	Yes	Yes	2703	Not specified
SnapNrack snapnrack.com	Both	100UL & 200UL	No	Yes	Grounding built into splices	2703	Roof: Many, see documentation; Ground: REC Solar
Solar Speedrack solarspeedrack.com	Roof/Shared rail system	SpeedMount	No	N/A (rails secure & ground modules)	No; one ground lug per rail required	467 & 2703	Hanwha modules evaluated
Spice Solar spicesolar.com	Roof	Spice Built-in Racking	Yes	N/A	N/A	2703 pending	Spice Solar-certified modules only (Auxin Solar)
Spider-Rax spiderrax.com	Both	Red Widow, Black Widow, Wolf Spider	Yes	N/A	N/A	2703	Not specified
Unirac unirac.com	Both	Solar Mount	No	No	Grounding built into splices	2703	Many, see documentation
Zep Solar zepsolar.com	Roof	All models	Yes	N/A	N/A	2703	Zep Solar compatible modules only
Zilla zillarac.com	Both	All except Cobra	No	No	Grounding built into splices	467	Any framed module in any Zilla mounting system (except “Cobra” mount)

Integrated Grounding & UL Listing

Racks with integrated grounding (IG) must be tested by a nationally recognized testing laboratory (NRTL) and listed to Underwriters Laboratories (UL) Standard 2703 for “Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels.” This is a new listing, and it allows module racks and clamping components to be evaluated and listed as grounding hardware. Because this listing is new and has been evolving for the last few years, you will come across different approaches detailing how to comply with this listing in manufacturers’ literature. Some manufacturers will list specific modules that were used in the testing process, others will not (see table).

Another listing that applies is UL 467 for “Grounding and Bonding Equipment.” Suitable lay-in lugs and bonding washers are listed to UL 467, and some grounding hardware used in IG solutions also carries this listing. Having the UL 467 listing allows those IG components to be used in multiple racking solutions, streamlining the UL testing process for each specific rack make and model.

Right: Bonding-path resistance testing is conducted on the Quick Rack integrated grounding system in an environmental test chamber.

Courtesy Quick Mount PV

Railless Mounting Systems

Some IG rack systems do not include rails, but use proprietary hardware to physically and electrically bond module frames together. Environmental and practical benefits include less material use (resulting in lower embodied energy); no awkwardly long rails to transport (long distance or to the job site), which decreases shipping costs and hassle; and no rail cutting or splicing kits are required. Additionally, once the learning curve is summited, overall installation time can also be reduced. PMC Industries, Quick Mount PV, S-5!, Spice Solar, Spider-Rax, and Zep Solar offer rail-free mounting systems (see table).

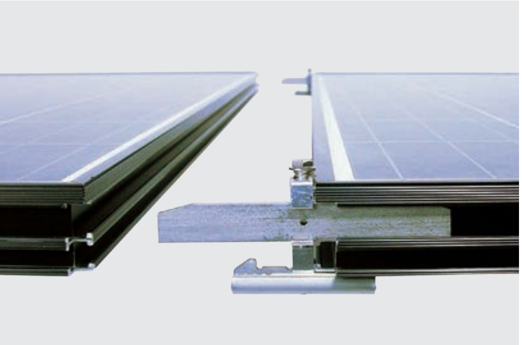
Some railless systems (such as Spice Solar and Zep Solar) require specialized (grooved) module frames. And, in general, railless systems include fewer wire-management options—there is no rail available to support wires or wire-management hardware, and some module frames don't have appropriate flanges on all sides. Since the module frames are tasked with providing the continuous grounding path, if a module is removed, an alternate grounding path must be implemented to make sure the rest of the array is still adequately grounded.

S-5! midclamps secure and electrically bond the PV module frames for a railless solution on standing-seam metal roofs.

Courtesy S-5!

Courtesy Spider-Rax

Spider-Rax's Red Widow system is a railless mounting solution for composite roofs.



Courtesy Spice Solar

Spice Solar offers IG via its "built-in racking system" for Spice Solar-certified modules.

Courtesy Quick Mount PV

Quick Mount PV's railfree rack system employs IG via its panel clamp (see opening page image). This system also offers an array skirt for a finished look.

It's been gratifying to watch the PV industry evolve over the last decade, and, with it, the equipment and installation innovations that have resulted. While PV racks with IG may not seem earth-shattering, PV installers know how time-consuming the array grounding process can be. It is easy to miss installing a lay-in lug or place a bonding washer on every module—and there's no visual reminder, as they cannot be seen post-installation. By removing these separate grounding steps, we are not only reducing materials and installation cost, but also helping ensure that PV arrays have a better chance of being appropriately grounded, creating safer installations. This makes a seemingly small evolutionary step in PV mounting a fairly large leap for the solar industry.

web extras

Grounding articles:

"Code Corner: Grounding & Bonding PV Systems" by Ryan Mayfield • homepower.com/152.104

"Code Corner: PV Grounding & Bonding; Part 2" by Ryan Mayfield • homepower.com/153.98

"Methods: Sizing Equipment Grounding Conductors" by Justine Sanchez • homepower.com/153.32

Rack articles:

"Pitched Roof Mounting" by Rebekah Hren • homepower.com/130.74

"Modern PV Roof Mounting" by Rebekah Hren • homepower.com/137.74

"PV Rack Innovations" by Rebekah Hren • homepower.com/151.52

"The Right Fit" by Jeff Tobe • homepower.com/161.44

Passive Solar Design

From a Passive House Perspective

Comment & Discuss this article @ homepower.com/166.44

by Katrin Klingenberg, with Graham Wright & Lisa White

The Passive House approach to passive solar home design optimizes a home's energy and economic performance with the three tenets of passive design—insulation, windows, and mass.

The Passive House (PH) high-performance design has two primary goals: minimize energy losses and utilize passive energy gains. A PH uses up to 95% less energy for space heating and cooling than a conventional house by using highly insulating materials; high-performance glazing; reducing thermal bridging; creating an airtight envelope; and heat/energy recovery ventilation. These strategies can keep a house warm passively with internal heat sources (people, lights, and appliances) and solar energy through the windows. Even the incoming fresh air can be warmed by an earth tube, for example.

The Passive House Institute US (PHIUS) technical committee and Building Science Corporation have researched economical passive design for North American climate zones. The results of that Department of Energy study can be found in the "Climate-Specific Passive Building Standards" report and will be incorporated into the PHIUS certification program in early 2015.

web extras

Access the full DOE "Climate-Specific Passive Building Standards" report at **bit.ly/PHIUSreport**.

PHIUS emphasizes Passive House methodology, rather than just passive solar. Designing for modest winter solar gain is part of the picture, but not the overriding feature as with homes that are classically passive-solar designed. The three tenets of passive solar design—a well-insulated envelope, optimal thermal mass, and high-performance and well-placed windows—are still important.

Good air-sealing practices, as well as ample insulation, are keys to developing an energy-efficient building envelope.

Courtesy PHIUS (2)

Insulation

Courtesy Steve Asher

Spray-foam offers good insulation value.

For Passive Houses, air-sealing and insulation are key, as these homes rely less on passive solar gain and more on limiting heat losses or gains due to air leakage. Dealing with air leakage produces straightforward results—the tighter the home, the less energy is lost or gained. Determining "ideal" insulation levels is more difficult, as it is highly climate-dependent and the right balance must be found between heating and cooling needs.

PHIUS is identifying new climate-specific passive building criteria that define cost-optimal characteristics, annual heating and cooling demands, and peak loads by climate. If a building meets the criteria for its climate, then its heating and cooling needs should be properly balanced. This criteria employs a fairly conventional economic analysis. It looks at total annualized cost—the projected energy bills plus the additional mortgage cost of the energy-saving upgrades over 30 years.

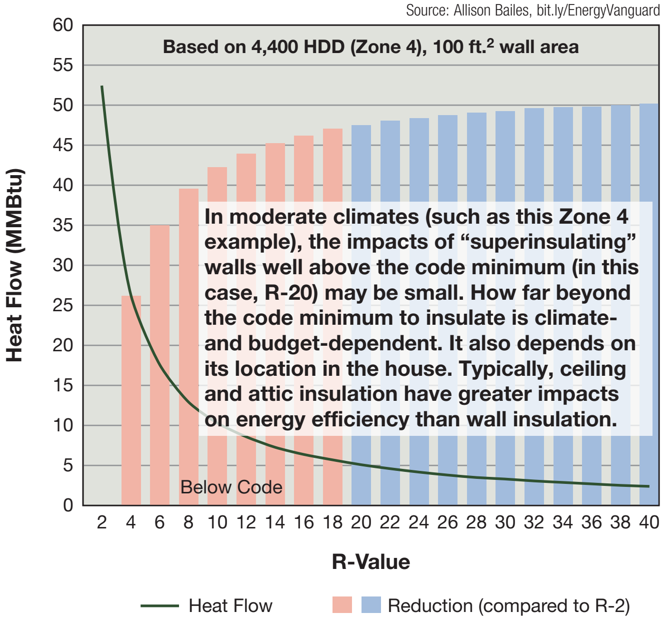
Some upgrades, like the first few inches of insulation, save more in utility bills than they cost to finance, and thus lower the cost of ownership. The economic break-even point is where the added finance cost equals the energy savings, and the total cost curve passes a minimum and heads back up. From an economic standpoint, a home can have too much insulation. Insulation provides diminishing returns—each added inch costs about the same but provides less energy savings (see the "Diminishing Returns of Adding Insulation" graph).

The "Cost of Ownership vs. Energy Savings" graph represents four homes: one built to minimum code standards, one that achieves net-zero energy, and two at points between. The one with the lowest point on the graph represents cost-optimal—where the additional cost of energy efficiency equals the energy savings realized features. The other middle point represents the situation in which the smarter economic investment would be offsetting energy use with solar-generated electricity, rather than more conservation/efficiency measures. There are future uncertainties and limitations of such a conventional analysis. Additional insulation (beyond strict economic concerns) offers resiliency to temperature swings and increased benefits in thermal comfort. And, because heating and cooling loads are reduced, a smaller PV system can be implemented to cover the building's loads.

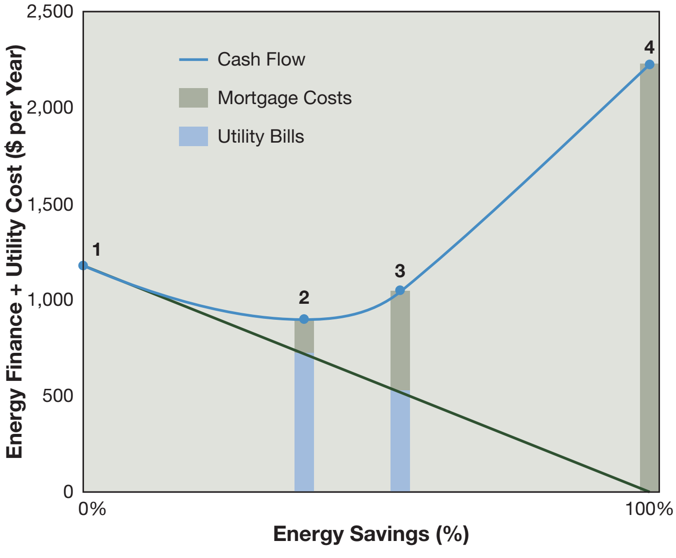
Tailoring insulation to a home's heating needs—rather than its cooling needs—is usually much more effective because there is more energy to be saved from it. The difference of interior temperature and exterior cold temperatures is greater (interior setpoint 68°F; exterior design temperature 10°F) than in the cooling case. In contrast, trying to achieve the same level of *cooling* via passive measures (insulation; external shades; natural ventilation) is difficult because the temperature difference (interior setpoint 77°F; exterior design temperature 90°F) is not as great. Usually, a heat pump for cooling is a far more cost-effective choice than passive measures, such as increased levels of insulation.

Diminishing Returns of Adding Insulation

Source: Allison Bailes, bit.ly/EnergyVanguard



Cost of Ownership vs. Energy Savings



Heat Load Calculators

"Product selectors" on heating equipment manufacturers' websites can help with calculations. However, those calculators often make middle-of-the-road or code-minimum assumptions, so they'll only give you a rough estimate. Pinning down heating and cooling load calculations isn't easily a DIY kind of thing, and even less so for passive buildings.

There are some software options available, but they can be complex. RETScreen (retscreen.net) is free from Natural Resources Canada. It's mostly focused on renewable energy, but it does have a conservation-measures project type. The free, but not easy to use, Department of Energy's EnergyPlus (bit.ly/DOEEnergyPlus) is a standard for building energy simulation. It has no graphical user interface, so you need to be comfortable with learning command language. We have used BEopt (beopt.nrel.gov), a free interface to EnergyPlus, for our standard-setting study. Both RETScreen and BEopt feature integrated economic analysis.

WUFI Passive (wufi-pro.com) was developed specifically for passive building assessment and verification. It is a two-part tool: the simplified, static energy performance and verification (based on monthly average climate data) portion, and the second, dynamic modeling portion based on hourly climate data, designed to address thermal bridging, moisture design, and thermal comfort—in addition to overall energy performance. It is currently not free, but parts of it will be in the near future.

Code Minimum vs. Superinsulated

PHIUS' new climate-specific standards that govern the level of passive measures (level of insulation, passive solar, shading, etc.) are resulting in buildings that, on average (and throughout all climate zones in North America), have an 86% lower annual heating demand and 46% lower annual cooling demand. Peak loads—which indicate a system's capacity—are 77% lower for heating; 69% lower for cooling. This is in comparison to a home built to meet the 2009 *International Energy Conservation Code (IECC)* level of performance.

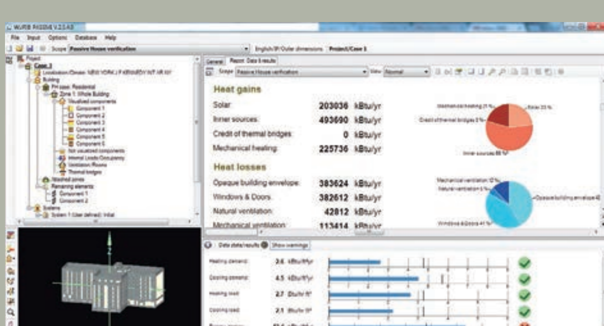
Let's look at an example comparison to code minimum. It's a 1,296-square-foot, one-story, all-electric house on Staten Island, New York, facing southeast on a pier-and-beam foundation. It has an R-40 floor, R-45 wall, R-90 roof, a solar heat gain coefficient of 0.50, and 136 square feet of R-6 windows. There is some seasonal exterior shading, an 83% efficient energy recovery ventilator, and it is air-sealed to 0.05 cfm_{50} per $ft.^2$ of envelope area. The result is a reduction in heating demand of 85%; cooling demand is cut in half. Needed heating system capacity ("peak load") is reduced by 80% and cooling capacity by 63%.

Courtesy Steve Asher

Structural insulated panels (SIPs) are one of the best-insulating wall systems, providing good R-value, limiting air infiltration, and minimizing thermal bridging.

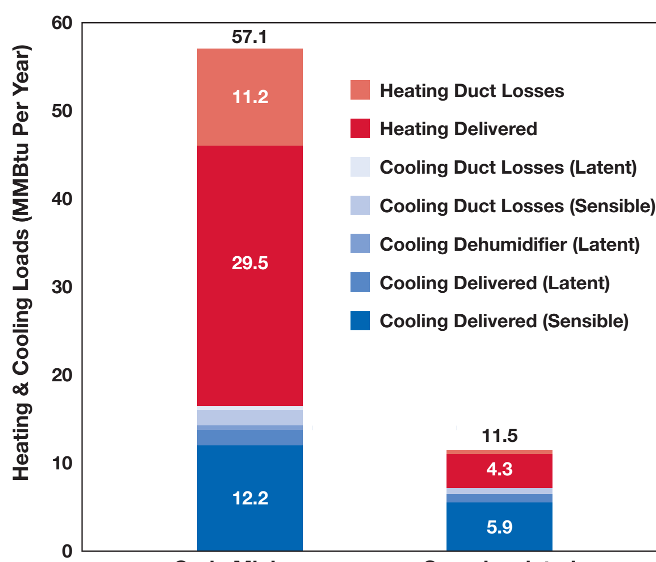
web extras

Find a more building energy modeling tools at **bit.ly/ModelingTools**.



Thermal modeling software like WUFI Passive can help determine a building's performance and show the results of changing design variables—in advance of construction.

Heating & Cooling: Code-Minimum vs. Superinsulated Homes



Thermal Mass

Thermal mass—materials like concrete and masonry that can absorb solar gain and radiate it as heat—is beneficial for thermal comfort because it dampens temperature swings. However, it does not make a significant difference in a Passive House's overall energy balance. The investment for adding significant amounts of concrete—beyond 4 to 5 inches of mass in the floor—has next to no payback. In a well-insulated and well-sealed home, the heat loss through the envelope is very low. The difference in temperature throughout the home should be slight—ideally no more than 2°F.

Compared to traditional passive solar design, the amount of south-facing glazing in a Passive House is modest. Total window area is approximately 15% of the wall area; up to a maximum of 40% of that total window area is south-facing, which avoids overheating. The appropriate thermal mass is also more modest as less solar gain is admitted. The minimized and relatively uniform peak heating loads can mostly be met with convective distribution assist from a balanced heat recovery ventilation system. A small space-conditioning system such as zoned minisplit heat pump is used to meet any higher heating loads that may occur.

Thermal mass still plays a role in comfort by modulating temperature differences in a building. In a Passive House, it should be evenly distributed and of modest thickness (0.5 to 1 inch) in multiple surfaces throughout the structure, rather than just one large surface in front of south windows, such as a 6-inch concrete slab.

Ben Root

In cooling climates, using higher levels of thermal mass can help reduce the need for mechanical cooling equipment.

Except in cooling-dominated climates, thermal mass floors should have a thermal break—be insulated—from the ground.

Courtesy Steve Asher

Mass in a Cooling-Dominated Climate

In cooling-dominated climates, Passive Houses use a variety of heat-avoidance strategies such as shading windows, reducing internal gains (by employing highly efficient lighting and appliances). Thermal mass effects are maximized by increasing the amount of distributed surfaces of greater thickness (1 inch of earthen plaster everywhere instead of gypsum board) and then accessing night-cooling and even earth-coupling (limiting insulation under the slab to the perimeter if any and leaving the slab in contact with the ground). WUFI Passive modeling shows that adding thermal mass can have a significant impact on overall energy balance, reducing annual cooling demand by up to 50% compared to typical Passive Home baseline without additional thermal mass. Additional thermal mass also increases thermal comfort by lowering peak cooling load conditions. Thermal mass in cooling-dominated climates has more beneficial impact than in heating-dominated climates.

In a paper published in the *Proceedings of the Ninth Annual North American Passive House Conference*, architect Dave Brach investigates the effects of various types of thermal mass used with a Passive House level of insulation in a home in Salt Lake City, Utah. He sought to determine if thermal mass, with natural nighttime ventilation (opening windows or employing a whole-house fan), would eliminate the need for air-conditioning units, and what level of thermal comfort

Courtesy Steve Asher

In this home, high-mass paperless cement board was used instead of traditional drywall to provide additional thermal mass.

and resiliency could be attained. Brach used WUFI Passive's dynamic modeling engine, which yields hourly predictions of a building's energy consumption, systems capacity needed, and thermal comfort.

He found that added thermal mass was effective in reducing peak cooling loads (the systems capacity and size needed to keep temperatures comfortable during the hottest day) in the spaces. Other strategies are controlling heat gains and losses through the envelope. This is dependent upon the level of insulation and whether earth-coupling is used. The next steps are to optimize window size and orientation and shading design, preserving daylighting, and minimizing thermal gains through opaque wall and window components. Then, peak loads for the zones of the building can be estimated.

Brach modeled different thicknesses and amounts of thermal mass for wall materials added for various natural ventilation rates. The materials used for walls were: drywall only; double drywall; 2 inches of concrete on all wall surfaces; drywall containing phase-change material (PCM); walls that had PCM packages (1.5 inches) behind the drywall; and concrete masonry unit (CMU) walls as interior partitions. All conditions were modeled for no natural ventilation and for ventilation rates between 0.75 air changes per hour (ACH) and 4.5 ACH.

Brach found that with sufficient temperature change through night cooling and sufficiently high ventilation rates (3.0–4.5 ACH), thermal mass is effective, with certain materials very effective in reducing (and, in some zones, eliminating) peak loads.

- Double drywall made little difference in peak reduction.
- 2 inches of concrete had a sizable effect.
- Changing to CMU partitions did not contribute significantly to a further decrease in cooling peaks.
- PCMs performed very well at the 3.0 to 4.5 ACH airflow rate, if integrated in the drywall close to the interior air.
- Adding more PCM behind drywall resulted in little additional reduction in peaks.

Glazing & Shading

Proponents of traditional passive solar design usually fall in one of two camps—"mass-and-glass" enthusiasts, who favor lots of south-facing glazing and maximum levels of direct-solar-gain thermal mass (such as Trombe walls; thick concrete slabs); and the "superinsulators," like physicist William Shurcliff, who advised building "light and tight"—using wood-framed structures and air-sealing strategies, such as dedicated air barriers and vapor retarders. His recommendations included sizing south windows to provide ample daylighting but not for maximizing solar gain.

PHIUS' climate-specific passive building standard development study modeled a 2,080-square-foot house with south glazing of 150 square feet, which is about 7% of the floor area.

SHGC Windows

Traditional passive solar design employed south-facing glazing with a high solar heat gain coefficient (SHGC) to allow the maximum amount of solar energy into the interior. In the

Courtesy Alpen

Right: High-performance windows are now achieving U-values as low as 0.09 (R-11), while still maintaining reasonable SHGCs.

past, having glazing with a high SHGC meant sacrificing the window's thermal performance (U-factor). It often required using insulating window shades at night and on cloudy days to prevent large heat losses. However, modern manufacturers have had success with coatings to provide both good thermal performance and a decent SHGC.

Cardinal Glass Industries offers its LoE-180 glazing, with a U-factor of 0.26 and SHGC of 0.69. Alpen High Performance Products manufactures an U-0.125 insulated window with SHGC of 0.556, and an U-0.09 window with SHGC of 0.492.

The PHIUS windows table shows current recommendations for window U-value and SHGC. The SHGC recommendations vary by climate and which direction the windows face. PHIUS' window-rating program maintains a distinction between true south versus off-south orientations, but its building performance standard-setting study doesn't rely on it in the modeling protocol.

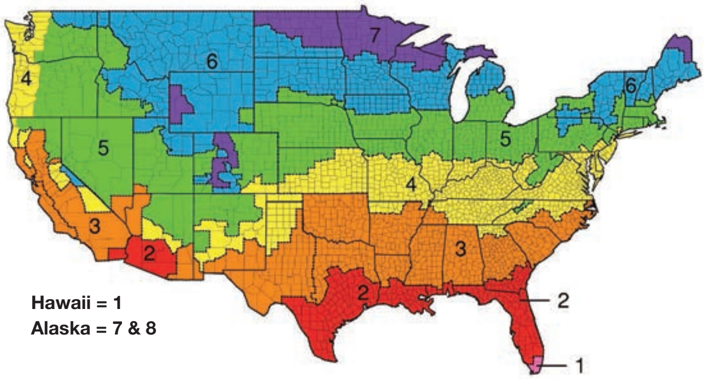
Climate Zone Window Recommendation Criteria

Climate Zone[1]	Overall[2] U-Value (Btu/ hr.-ft^2•-F)	Glazing[3] U-Value (Btu/ hr.-ft^2•-F)	SHGC[4] South-Facing	SHGC[4] Non-South
8	≤ 0.11	≤ 0.10	≥ 0.50	Any
7	≤ 0.12	≤ 0.11	≥ 0.50	Any
6	≤ 0.13	≤ 0.12	≥ 0.50	Any
5	≤0.14	≤ 0.13	≥ 0.50	Any
4	≤0.15	≤ 0.14	≥ 0.50	≥ 0.40
4 Marine North	≤0.16	≤ 0.15	≥ 0.50	≥ 0.40
3 Marine South	≤ 0.22	≤ 0.20	≥ 0.50	≥ 0.30
3	≤ 0.18	≤ 0.16	≥ 0.50	≥ 0.30
2 West	≤ 0.18	≤ 0.16	≥ 0.30	≥ 0.30
2 East	≤ 0.20	≤ 0.18	≥ 0.30	≥ 0.30

[1]ASHRAE/IECC/DOE; [2]Installed window, including frame; [3]Center of glass; [4]Solar heat gain coefficient

Courtesy PHIUS (3)

U.S. Climate Zones



Properly shaded south-facing glazing may take many forms, from overhangs to porches to pergolas, but the end goal is the same—preventing excess heat gain during warmer months.

web extras

PHIUS-recommended windows are listed on its Product Data Certification database at **bit.ly/PHIUSwindows**.

Shading Strategies

In cold and mixed climates, overhangs are critical in reducing summer solar gain. Because passive buildings are so well-insulated, any gain during warm weather can potentially turn into a cooling load.

Overhangs are most effective for shading south-facing glass, but not so effective for east and west windows due to the lower sun angles at the start and end of the day. An exterior shade or blind is recommended for east and west glass. In cooling-dominated climates, covered porches, rain screens, and vented roofs can further reduce heat gain.

Interior blinds are not as effective because they allow radiation into the living space, only reflecting some of it back out. Blinds and exterior shading devices can be effective, but rely on human interaction. Fixed shading such as fins, overhangs, grilles, etc., may be more effective.

Key Strategies

Adapting a home's design to local climate considerations and the particulars of the site (i.e., solar orientation), and then implementing the keystones of Passive House and passive solar design, can help ensure your home has the best chance of maintaining good thermal comfort, no matter what the season.

web extras

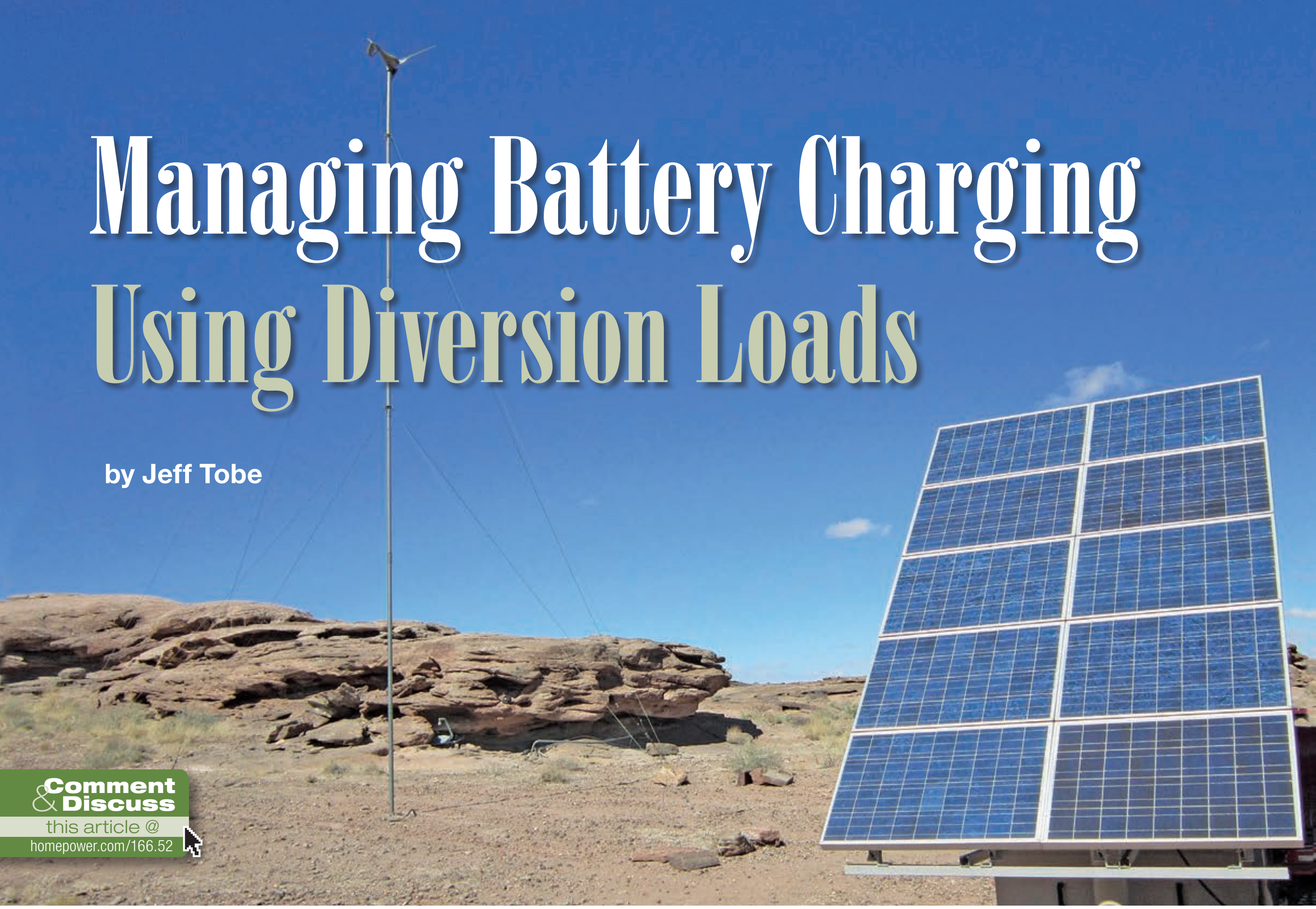
"The Passive House: Strategies for Extreme Efficiency" by Katrin Klingenberg • **homepower.com/138.70**

"Breaking New Ground with a Passive House" by Katrin Klingenberg • **homepower.com/138.94**

"Sun-Wise Design: Avoiding Passive Solar Design Blunders" by Dan Chiras • **homepower.com/105.38**

Managing Battery Charging Using Diversion Loads

by Jeff Tobe



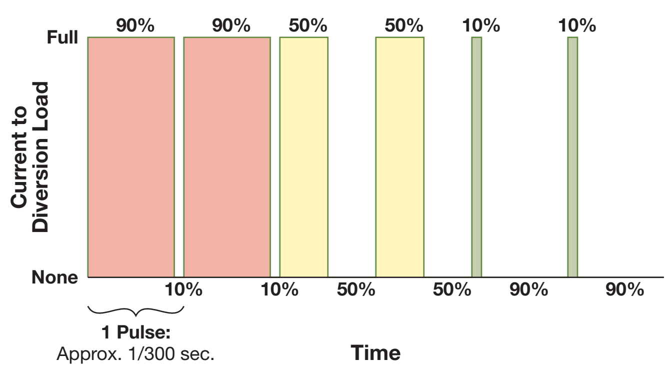
Jeff Tobe

PV charge regulation can be relatively simple: When the batteries are full, the controller disconnects the PV array. Adding wind or microhydro to the system makes charge regulation more complicated, since turbines may overspeed if unloaded. Often, diversion control is the solution. Off-grid "hybrid" combinations of solar, wind, or microhydro have been around for decades. These renewable electricity systems can power buildings and other sites far from the electrical grid. But hybrid systems can present unique design challenges, since multiple sources of generation—for example, a PV array, wind turbine, and a backup generator—increase the complexity of how to control battery charging so your batteries don't get overcharged, and damaged.

In a PV system, the charge controller is placed between the energy source and the battery. Its job is to regulate the voltage and current coming from the energy source to charge the battery and protect the battery from overcharge (and damage). Modern charge controllers have a three-stage charge cycle. During the "bulk" phase, the voltage rises to the bulk level while the batteries draw maximum current. Once this level is reached, the absorption phase begins: the voltage is maintained at the bulk phase level for a specified time, while the current tapers off as the battery reaches a full charge. Once the battery is fully charged, the voltage drops to the float level and the battery only draws a small current until the next cycle.

Today's charge controllers mostly use pulse width modulation (PWM) to control current into the battery. Pulses of current in rapid succession are allowed to pass from the energy source to the battery (or from the battery to the diversion load—more on this to follow). The controller cannot limit the size of this current, but instead controls the duration so that it can achieve the correct average current in the circuit. By modulating the width of the pulses, the controller regulates the battery charge rate. The target is to maintain the correct battery voltage for the prevailing stage of the charging cycle.

Pulse Width Modulation: Example Ratios



Note: Pulse width ratios are infinitely variable. Three examples shown.

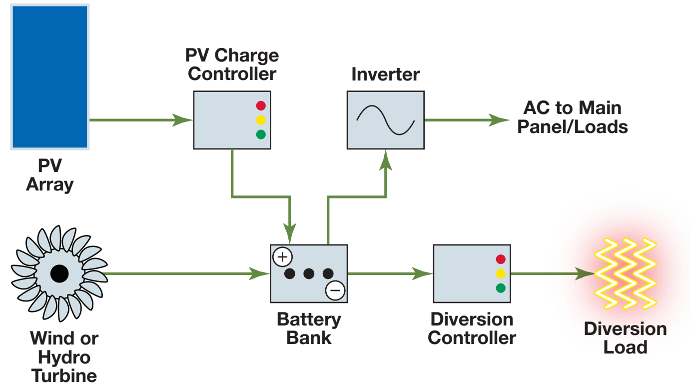
Some charge controllers also offer maximum power point tracking (MPPT), which no longer chains the input voltage to the output voltage. By doing so, it potentially allows more energy to be harvested from the generating source.

With a PV array, charge control regulation is fairly straightforward. When the batteries are full, the controller throttles the voltage/current accordingly to prevent overcharge, turning off the array in a sophisticated way. Chargers and inverter/chargers connected to generator power control the charge rate in the same way, limiting the load on the generator to regulate the charge rate. But charge control with wind and microhydro turbines is more difficult, since some turbines can overspeed when unloaded (i.e., disconnected from the battery). In an unloaded condition, a turbine will "freewheel," increasing rpm and voltage. Excessive freewheeling can damage bearings and rotor components, and harm the electronics with the high voltage that's produced. Turbine output must remain connected to a load at all times, yet not be allowed to overcharge the batteries. And this is most effectively accomplished with a diversion controller.

Diversion-Load Control Options

Diversion controllers are an effective method for managing wind or hydro turbine output and preventing battery overcharge. The turbine output is connected directly to the battery, in parallel with a diversion load controller (usually separate from any PV controller). This device shunts excess energy from the battery to a diversion (aka "dump") load, usually a large resistor in air or a water-heating element, either of which is sized to enable constant turbine operation at its full output.

PWM Diversion



Some PV charge controllers can be reconfigured as diversion controllers for managing turbine output. Commonly available models range in size from 35 to 60 A for various nominal (12 V, 24 V, 48 V) battery voltages. These controllers typically allow field-selection of battery voltage; mode of operation (charge, load, or diversion control); and voltage setpoints for battery charging or load management. Often, a combination of dip switches, jumpers, and potentiometers are used to adjust these settings.

Programming the controller diversion setpoints is the same as setting the charging setpoints for a PV system. The goal is to set the bulk- and float-charge parameters to ensure full battery charging—without overcharge. However, if two separate controllers are being used, it may take a little time to adjust these parameters to keep the two units working together properly. It may be helpful to program the diversion controller to slightly higher or lower setpoints than the

Courtesy Schneider Electric

The Schneider Electric C-series of PWM charge controllers use two potentiometers for adjusting the battery-charge setpoints—one for bulk and one for float charge. This allows fine-tuning to match a wide range of battery types.

Courtesy Morningstar

Morningstar's TriStar units offer a wide range of factory-setpoint configurations through a series of dip switches. Custom programming can be performed if necessary through an RS232 connection to a laptop running Morningstar's free MSView software. The TriStar maintains a very stable battery voltage through gusts of wind. It has built-in datalogging functions and optional add-on data display and auxiliary relay hardware.

solar controller so as to encourage or discourage diversion of power to the dump load as desired. For example, a 48 V system with flooded batteries that has the PV bulk charge set to 58.4 V could have the diversion controller set to divert power during the bulk-charging cycle at 58.6 V so as to minimize diversion of PV power. Or vice-versa—for example, if we want to maximize the energy capture into the dump load for water heating. Float- and equalize-charge setpoints would be fine-tuned in a similar manner, but bear in mind that the two units may not agree on the timing of these stages of charge. The default strategy is to set the two devices to the same setpoints that best suit the battery charge regime.

Using the Aux Output for Turbine Control

Commonly used in PV systems, maximum power point tracking (MPPT) charge controllers may also offer options for turbine control. MPPT means that the input voltage of the controller is adjusted to maximize the PV array's productivity. This function is independent of the actual charge control process and offers the advantages of higher-voltage transmission as well as enhanced energy production. On the charge control end of things, most PV charge controllers have at least one auxiliary output feature for diversion control of battery charge rate. Blue Sky Energy, MidNite Solar, OutBack Power, and Schneider Electric all have MPPT models with auxiliary output and programming to support diversion-load applications. This allows for the connection of turbines and/or for maximizing energy usage by diverting excess solar energy to useful heating. Blue Sky Energy offers its Duo Option Diversion Control upgrade component, which converts the auxiliary output for its Solar Boost 3024 controller into a 20 A diversion control. This unique conversion allows simultaneous MPPT operation for the PV array while also diverting up to 20 A through the converted auxiliary output. (Note this controller model is limited to 12 V and 24 V battery systems.) This can be a good solution for a smaller system, since it minimizes the space required for control equipment. Another upgrade option can increase the diversion capability to 40 A.

AC Heating Elements Used in DC Systems

Standard AC water heating elements may be used if DC models are not available. However, it is important to remember to adjust the power rating to match the system voltage. For example, a heating element rated at 120 V and 3,500 W is common in residential electric water heaters. If this same element is connected to a 48 V system as a diversion load, the power capacity will be reduced significantly. To determine the new power rating of the heating element, a voltage ratio is applied to the original power rating:

Power equation: W = V × A, so first figure out the current draw of the element:

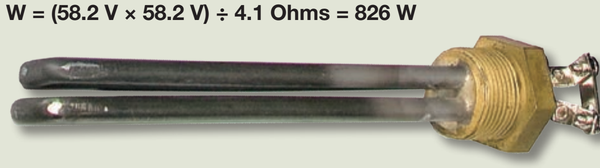
3,500 W ÷ 120 V = 29.2 A

Then, find the resistance of the element with Ohm's law: V = I R

120 V ÷ 29.2 A = 4.1 Ohms

Using 48 V nominal power source (when batteries are full, V = 58.2), combine Ohm's law and the power equation: W = (V × V) ÷ R

W = (58.2 V × 58.2 V) ÷ 4.1 Ohms = 826 W



Shawn Schreiner

Though often harder to source and more expensive, DC-specific immersion heating elements are available.

Diversion Load Calcs

Let's size a diversion load for a turbine that has an output of 1,000 W at 48 V nominal battery voltage. First, calculate the diversion controller's minimum amperage rating. The controller will be diverting at about 56 volts, so we can find the current:

Wattage ÷ Voltage = Amperage

1,000 ÷ 56 = 18 A

Next, multiply the amperage of all your uncontrolled charging sources by a safety factor (the *NEC* recommends 150%, which translates into multiplying by 1.5). In this case, the turbine is the only uncontrolled source, since the PV array has its own controller.

18 A (the turbine's output) × 1.5 (safety factor) = 27 A

The diversion controller's minimum amperage rating would be 27 A.

The minimum amperage for the diversion load will also be 27 A; the maximum will be the actual controller rating (which might be 30, 40, or 45 A)—it is essential that the diversion load never be sized larger than the controller's amperage rating to ensure the load doesn't overwhelm the controller.

Our choice of controller and of load(s) will be governed by what parallel combination of loads we can obtain that fit within these calculated limits.

For example, if we can obtain two loads, each rated 14 A at 56 V, then we can use these with a Xantrex C-30 charge controller.

Courtesy Blue Sky Energy

Blue Sky Energy's Duo Option diversion control upgrade converts the auxiliary output for its Solar Boost 3024 controller into a 20 A diversion control.

Dedicated MPPT Controllers for Turbines

MPPT voltage conversion can also be used to maximize turbine output in some cases. Some MPPT controllers can track microhydro turbine output by adjusting a few setpoints. In this application, the turbine's DC output would be connected directly to the charge controller's DC input, much like a PV array. MidNite Solar and Morningstar also offer wind turbine MPPT functions in some of their controllers. However, wind turbine output cannot be tracked to find maximum power. The installer must enter values or a "power curve" into the controller's memory to suit the particular wind turbine.

MidNite Solar's integrated solution couples its Classic charge controller with the "Clipper" add-on. This unique solution can be used for both wind and microhydro applications. The Clipper provides protected DC input into the charge controller, which in turn performs MPPT-like management of the turbine for maximum power output. Advantages include built-in components, such as diversion load, solid-state relay, and a run/stop breaker. The Clipper is similar to the integrated diversion controls offered with some wind turbines. Units are available in DC and AC options. AC models rectify the turbine's wild AC output into controlled DC input for the charge controller to process. The resistor bank can be configured to match the turbine's output, and multiple units can be paralleled for larger turbines.

Right: Morningstar's MPPT 600 TriStar controller can accommodate a wind system, but does not have aux outputs for diversion control.

Courtesy Morningstar

Courtesy MidNite Solar

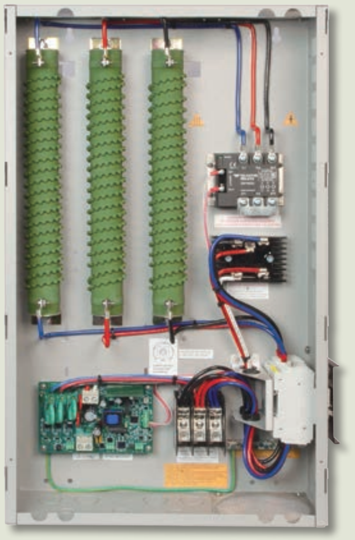
Above: MidNite Solar's Classic controller has two aux outputs, and can also accept wind turbine input.

Courtesy OutBack Power Systems

Right: OutBack Power's FLEXmax series has the ability to control diversion via its aux output.

Wind Turbine Output

Wind turbines are either designed for batteryless grid-tie or are configured with DC output to match common battery voltages. Depending on which, the integration equipment varies. The best wind turbines come with their own control packages to manage the turbine output. Buying a wind turbine without controls designed specifically for it is not the wisest plan, but if you do, make sure the electronics you buy will actually work with the system.



MidNite Solar's Clipper can be used with turbines that do not come with their own control integration package/equipment.

Courtesy MidNite Solar

Morningstar has a variety of controllers designed for MPPT for PV and wind systems, including the MPPT 600 V TriStar controller. This controller has a battery output rating of 60 A and also can be paralleled (up to four units) for larger wind units. However, these controllers do not have auxiliary outputs for diversion control, nor does Morningstar offer DC voltage protection add-ons. OutBack Power's FLEXmax series (60 and 80 A models) can be used for hydro but not wind. They do have diversion features but no protection add-ons, so it is important to ensure that the turbine output cannot exceed the Voc of these controllers.

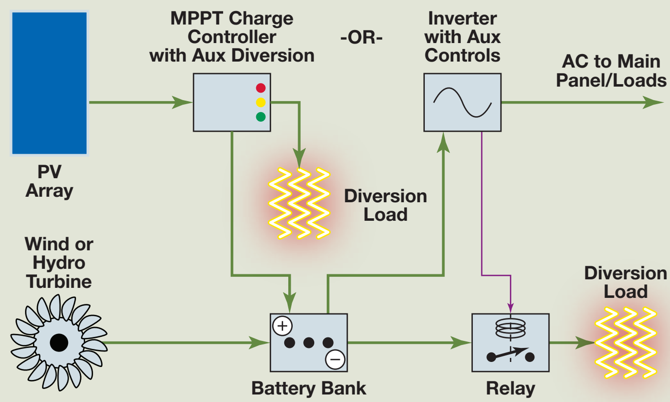
Auxiliary Circuit-Based Diversion Using Relays

Many inverters and MPPT charge controllers come with programmable auxiliary outputs, which can enable relay control for a variety of applications, including diversion to prevent battery overcharging (operating at battery-voltage setpoints). The number of auxiliary outputs is limited by the hardware and may also be needed to control generator starting or a ventilation fan for the battery enclosure. If there are not enough auxiliary outputs, a Morningstar Relay Driver can be used to add more.

Auxiliary outputs are typically limited to low power, but they can be used to operate suitably chosen power relays that divert higher power to a resistive element or another load during times of surplus power production. Whether these loads are DC ones, or AC ones connected to the inverter's AC output, they can divert energy from the battery and achieve charge control while harvesting surplus energy.

Pumping water into storage for domestic use and/or irrigation is a smart use of your system's excess power. Motor loads such as a water pump typically require an on/off mechanical relay because they are not likely to work on PWM, while resistive heating loads are best suited for solid-state relay control.

Auxiliary Diversion Options



Diversion Load Control Approaches

The wind and/or microhydro turbine and the type of charge controller used for the PV array are two main factors in determining an optimal diversion-control strategy. For a PV array and a turbine with DC output, a common scenario is to use an MPPT charge controller for the array with an auxiliary output to control diversion of turbine energy. Used with a relay and an air-heating diversion load, this is one of the most economical, and easiest, approaches. Depending on the voltage and wattage ratings, an air-heating dump load with a wattage range between 1,000 W and 2,100 W can cost between $150 and $250; a suitable DC-rated relay may cost about $50. Mounting a prefabricated air-heating diversion load can often be much easier than retrofitting a DC circuit to a water heater tank.

For larger systems, multiple dump loads may be necessary to handle full output diversion from the turbine. The number of relays and the number of dump loads will depend on their power ratings. Loads can be paralleled to achieve a sufficient capacity. In smaller hybrid systems, or ones that receive only seasonal use, a separate PWM controller for managing the turbine and preventing battery overcharge is common, since these systems may not be able to fully realize the advantages of MPPT charge controllers. This system type could be designed with two separate PWM controllers—one unit manages the PV array, and another manages output from the turbine. Costs depend on the size and model. For a 24 V system with turbine output of 25 A or less, a basic PWM controller rated for 40 A with a 25 A to 40 A diversion load would cost about $300. Adding another PWM controller for the PV array brings the cost to $450—still less than most MPPT controllers, which typically start at $550.

Ian Woofenden

Though some aux circuits on MPPT controllers and inverters cannot handle the amperage of a large diversion load, they can control a relay that can handle higher voltage or current.

Diversion Load Sizing

Properly sizing the diversion load is fairly straightforward, but important—if too small, it will not divert all of the turbine power, subjecting the battery to overcharge. If the diversion load is too big, it could overload the controller and cause it to disconnect, leading to unregulated battery overcharging. Add up all of your uncontrolled charging sources (i.e., wind turbine and/or microhydro turbine), then include a safety factor—the 2011 *National Electrical Code (NEC)* suggests adding a safety factor of 150%. (This factor accounts for potential spikes in output and provides longevity of the load component since, under normal turbine operation, the load would only be operating at two-thirds capacity.) Then, choose a diversion controller with a rating equal to or higher than this (see an example in the "Diversion Load Calcs" sidebar). Choose a diversion load equal or higher to this, but not any higher than the controller's capacity.

Using Your Diverted Energy

Stand-alone renewable energy systems suffer a bit of a disadvantage in relation to grid-tied ones, which is that much of the energy they can produce will be wasted when the battery is full. With grid-tied systems, the excess is always exported; with stand-alone systems, you have to use it, or lose it. True conservationists will tailor their usage habits relative to the battery voltage, effectively acting as human diversion controllers, with a mission to maximize the effective use of precious energy: washing clothes, sawing firewood, running the vacuum cleaner, when the wind is blowing or the sun is blazing.

But not everyone wants to have their lives dictated by battery voltage. How can we automate usage and prevent wasting energy? The obvious answer is to use the surplus as a useful source of heat, which is the secondary function of diversion loads, which create heat energy from surplus electricity. Often, these devices are simple wire-wound resistors, installed in the power shed, that "dispose" of the energy surplus safely and economically. We can harvest some (or all) of this heat and avoid burning fossil fuel to heat water or to keep warm.

Two main types of diversion loads are air-cooled resistors and water heating elements. The advantage of air-cooled resistors is that they are always available (nobody will turn them off). But PWM-driven wire-wound resistors tend to be noisy, and their whining is usually unwelcome in a living space, so this heat is usually just "dumped" into a power shed.

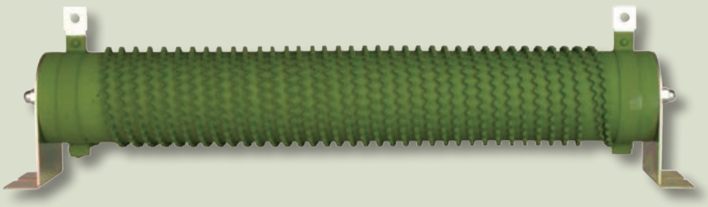
Water heating elements in a water heater tank are another type of diversion load. They can provide water heating and perhaps space heating. If your renewable energy system is adequately sized to maintain the battery at a healthy state of charge, quite a bit of surplus heat energy will be available to divert. The disadvantage is that you cannot readily put a thermostat on these heaters because they must always be available to control battery charge, and they will be working on DC, which may damage the thermostat.

Ian Woofenden

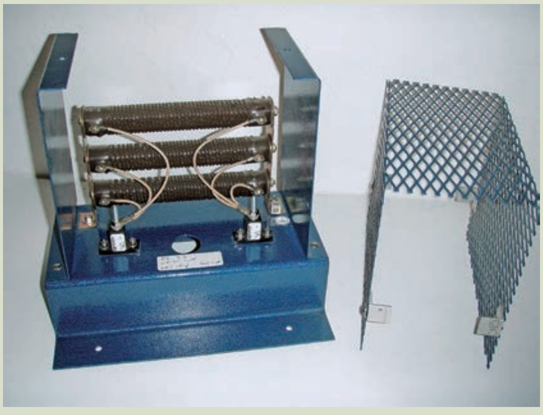
An air-resistance heater diversion load (inside a protective cage) is mounted above the power-conditioning components of a wind/ PV system.

To use the output of the diversion charge controller directly, you will need to obtain special elements designed to work at lower voltage, or put up with much lower power output from heaters designed to work at grid voltage—for example, 120 VAC heaters will only yield one-quarter of the heating capacity if operated at 60 VDC.

Air Resistance Elements

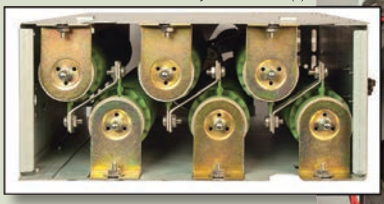


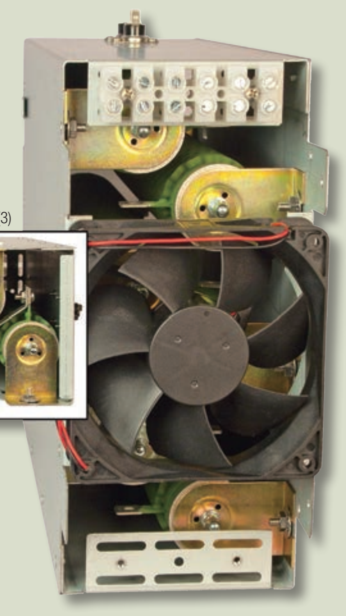
Below: An Alternative Power & Machine resistance heater unit for hydro systems.



Ian Woofenden

Courtesy MidNite Solar (3)





Above and right: An individual resistor and a six-element cage with circulation fan by MidNite Solar.

web extras

"MPPT charge controllers" by Zeke Yewdall in *HP162* • **homepower.com/162.52**

"2012 Charge Controller Buyer's Guide" by Dan Fink in *HP146* • **homepower.com/146.106**

"Wind-Electric Systems Simplified" by Ian Woofenden in *HP110*

"Microhydro-Electric Systems Simplified" by Paul Cunningham & Ian Woofenden in *HP117*

"The Electric Side of Hydro Power" by Jerry Ostermeier & Joe Schwartz in *HP126* • **homepower.com/126.68**

Manufacturers

Apollo Solar • apollosolar.com

APM Hydro • apmhydro.com

Blue Sky Energy • blueskyenergyinc.com

MidNite Solar • midnitesolar.com

Morningstar • morningstarcorp.com

OutBack Power • outbackpower.com

Schneider Electric • solar.schneider-electric.com

Solar Converters • solarconverters.com

The solutions to this problem are many and various. One option is to obtain specialized low-voltage heating elements, or use inverter power to operate grid-voltage elements via a relay. In the low-voltage case, you can use a changeover relay to shift the power to an air-heating element when the water heater thermostat opens, or you can design a water system that copes with the excess heat without the need for a thermostat. In the inverter-powered case, you can prioritize diversion to hot water via the inverter, but program a backup diversion at battery voltage that takes over after the water reaches a certain temperature.

Diversion control of battery charge is more than just a way to deal with renewable energy from turbines. It's an opportunity to increase the efficiency of your energy system by automatically using any energy surplus. The amount of effort you put into this needs to be commensurate with the gains, but in the case of hydro turbines, for example, there can be a very large amount of surplus and it is well worth doing.

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Rapid Shutdown of PV Systems: Part 2

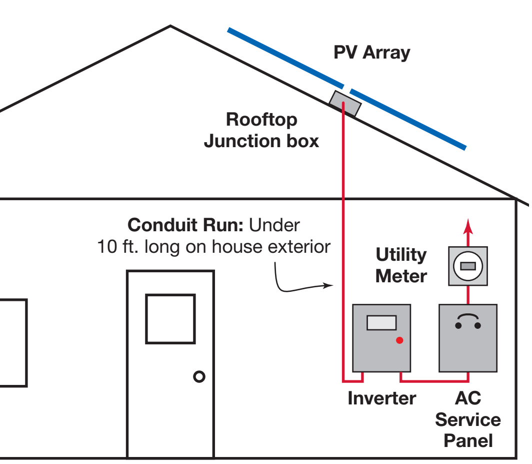
by Brian Mehalic

In *HP164*, "Code Corner" discussed the requirements of Section 690.12, "Rapid Shutdown of PV Systems on Buildings"—a new section of the *National Electrical Code (NEC)*. This article covers options for meeting this requirement for common types of residential PV installations. The *NEC* doesn't specify exact compliance methods—there is no single "rapid shutdown initiation device" (RSID) or strategy. In most cases, there is more than one way to meet this requirement and options will vary depending on the system type. Proper planning and consultation with the local authority having jurisdiction (AHJ) will help ensure that this requirement is effectively implemented.

Section 690.12 does not specify the location of equipment used to meet the rapid shutdown requirement. However, the goal of rapid shutdown is to help firefighters and emergency responders protect themselves—so it makes sense to group any additional rapid shutdown switches with the main AC service disconnect, or wherever responders will go to control the utilities that supply the building. For stand-alone systems, locating the shutdown means in an easily visible, accessible, and well-labeled location meets the spirit of the requirement.

Batteryless Grid-Tied Systems

Meeting Section 690.12 requirements for batteryless, grid-tied systems that are interconnected on the load side of a service is fairly straightforward. The strategies and equipment used depend on the inverter and system topology. Supply-side connections are addressed later in this article.



If you can install a string inverter within 10 feet of the PV array, as shown here, you do not need to install any remote switches to comply with 690.12.

String inverters. Fulfilling 690.12 requirements in systems with string inverters depends on the equipment layout. If the inverter is mounted on the roof within 10 feet of the array or on an exterior wall within 10 feet of the array; the AC connection to the inverter is de-energized when utility power is shut down (also shutting down the inverter, as is typical with these systems); and if DC capacitance in the inverter is not an issue (see below) then no additional device is required to control the PV system conductors. Per 690.56(C), a label (ideally at the main AC service disconnecting means) to alert emergency responders must state: "PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN."

Providing additional information is also helpful, such as: "Disconnecting AC service to the building also isolates energized PV system conductors to within 10 feet of the PV array." Including a map that shows the array's outline, its location on the roof, and the 10-foot perimeter is also helpful for emergency responders.

If the string inverter is located beyond 10 feet of the rooftop array or is connected to the array by DC circuits that run for more than 5 feet through a building, some means of automatic disconnection for the DC conductors, whether they be PV-source or -output circuits, must be provided. A rooftop-mounted, remotely controlled disconnect, as allowed in *NEC* Section 690.15(C) and 690.17(A), would suffice. This could be a contactor; shunt trip switch or breaker; or power-operated switch or relay. This normally open disconnect would be closed when utility power is present. If AC power to the building is shut off, the disconnect automatically opens and de-energizes the conductors from the disconnect to the inverter. Note that additional control wiring will need to be run to the disconnecting device; if the device is in a combiner box and also is locally operable, then it could also fulfill the 690.15(C) requirement for a disconnect at roof-mounted combiner boxes.

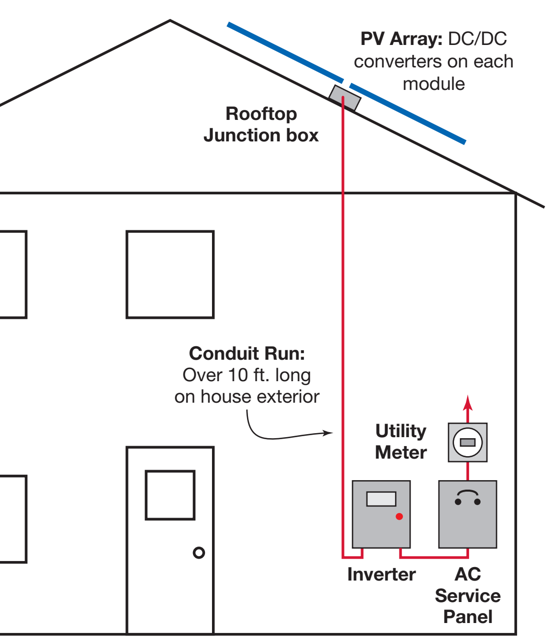
In some inverters, DC capacitors can energize DC circuit conductors after the inverter is off. Unless the inverter capacitors discharge to less than 30 V within 10 seconds, those same conductors that are controlled within 10 feet of the array (or 5 feet into the building) must also be isolated at the inverter to protect first responders from capacitive charge in the inverter. Contact the inverter manufacturer for details, as some types (such as transformerless) and brands of inverters are available that do not remain energized on the DC side after being shut off.

If there is DC capacitance beyond the allowances of 690.12, then a second switch, operating in conjunction with the rooftop disconnect, is required. A DC disconnect, wired in series to operate with the rooftop disconnect when the main AC disconnect is shut off to the building, and also manually operable to function as a DC equipment disconnect for the inverter, would be the ideal approach.

This disconnect, which isolates the DC side of the inverter, must be located at the inverter. If the inverter is inside the building, then remote operation of this disconnect is required. It must open when AC power is shut off to the building or a separate RSID must be installed. If so, group it with the main AC service disconnecting means, and clearly label both.

MLPEs. Most microinverters, DC-to-DC converters, and other types of module-level power electronics (MLPEs) already meet 690.12 without needing additional components. Upon loss of utility power (or operation of a DC or AC disconnect), the MLPE also shuts down, limiting the voltage to that of a single module (or less) and isolating conductors with voltage to those behind the modules. However, if an array with MLPEs is connected to a string inverter, it must be verified that the string inverter's DC input capacitors either discharge to less than 30 V in 10 seconds, or that they are isolated from the DC circuit conductors, as described above.

Supply-side connections. There is a critical distinction between PV systems connected on the supply side versus those connected on the load side. In most cases, shutting off the AC service will activate rapid shutdown for properly designed load-side-connected systems. But those connected on the supply side may remain energized—and even continue to operate, depending on how they are connected and how the utility service is shut off. Sections 705.10 and 705.31 require a directory, disconnecting means, and overcurrent protection at the point of supply-side interconnection. This supply-side PV system disconnect can also function as the RSID provided operating it causes the initiation of the shutdown events detailed previously. Because this is an additional switch that must be operated to de-energize conductors in the building beyond the main AC service disconnect, it should be grouped with the main AC disconnect. Both should be clearly labeled. In addition to the language required by 690.56(C), the label should convey the following information and have a diagram, if appropriate: "PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN. Turn off PV system disconnect (located XXX) to isolate energized PV system conductors to within 10 feet of the PV array."



MLPEs are well-suited for rapid shutdown. In this scenario, shutting off the AC service to the building shuts off the inverter and isolates DC conductors to the module level.

Battery-Based Systems

Battery-based PV systems operate completely without the grid (stand-alone) or continue to operate when the grid goes down (grid-tied with battery backup, or multimode). The simple solution of cutting grid power to activate rapid shutdown of the PV circuits (which can be used for batteryless systems) isn't a solution for battery-based systems—so implementing 690.12 is more difficult when energy storage is involved.

Grid-tied systems with battery backup require an RSID that enables the system to stay on when the utility power goes out. In an emergency, however, the switch, along with the utility service, can be shut off. Clear labeling of both is critical so that emergency responders are aware of the PV system, and where to shut it off. Locating the means for shutting down the PV system at the same location as the disconnecting means for the AC service enhances functionality.

PV source and output circuits still need to be controlled as described for batteryless systems. Further, the conductors between the batteries and the inverter and/or charge controller must be controlled if they are inside a building and longer than 5 feet. This switch may have to be rated for 250 A or more (and the appropriate DC voltage), depending on the system configuration. Shutting off the batteries in this manner will also shut off the inverter's AC output. This disconnect, properly located and with overcurrent protection, can also fulfill the 2014 Section 690.71(H) requirement.

Battery circuit conductors that are less than 5 feet long are not subject to control during rapid shutdown. However, the inverter will still need to be shut off or its AC output disconnected within 5 feet of the inverter when rapid shutdown is initiated.

Stand-alone systems must also comply with 690.12, and visibility and labeling of the rapid shutdown means are even more critical as there is no utility service and the PV system entrance point (or even its presence) may not be obvious. A well-labeled RSID—which isolates battery conductors to within 5 feet of the battery; shuts off the inverter output; and isolates DC PV circuits as described above—would be required.

Labeling, Location & Safety

Section 690.12(5) requires that "equipment that performs the rapid shutdown shall be listed and identified." Per Section 690.4(B), all PV systems equipment has to be listed; this requirement is repeated throughout 690. However, there is no specific "rapid shutdown listing" for equipment. The intent of the listing requirement in 690.12(5) is more general, allowing a range of products and solutions to be used. Examples include: a DC contactor combiner box that is listed to UL1741 and contains manufacturer-assembled components rated for the application (i.e., the current and voltage as calculated per the relevant *NEC* sections); or for inverters installed within 10 feet of the array; or for various MLPE devices; or for other suitable, listed products installed in accordance with their instructions and ratings.

Section 690.56(C) details the labeling requirement for rapid shutdown. While the *NEC* language suggests that this label is necessary only for grid-tied PV systems, best practice would be to label the rapid shutdown location and equipment on stand-alone systems as well, including at the same locations as the labeling required by 690.56(A).

In concert with labeling requirements of the International Fire Code (IFC), Section 690.56(C) specifies that labels regarding rapid shutdown be:

- reflective
- white lettering on a red background
- in all-capitalized lettering at least 3/8 inch tall

The required wording is "PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN." This is the bare minimum. Provide additional details for emergency responders if an RSID beyond the main service disconnect needs to be operated to initiate or achieve rapid shutdown, and label both. Remember, be clear and concise—this information is for emergency responders.

PV system safety should be the concern of everyone in the industry. While the new rapid shutdown requirements may add cost to some systems, there are opportunities to satisfy multiple *NEC* requirements simultaneously, and opportunities to enhance the safety and serviceability of our systems.

web extras

"A Peek at the *2014 NEC*—Part I" in *HP158* discusses terminal limitations and 75°C lookup • **homepower.com/158.86**

"Rapid Shutdown of PV Systems: Part 1" by Brian Mehalic • **homepower.com/164.68**

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Creek Chic

by Kathleen Jarschke-Schultze

January 2015 marked one year since Bob-O and I retired. Before we retired, we vowed to hit those lists of projects that would take more than a weekend to complete—a luxury Bob-O had not had before. Our lists shrunk and have grown again, but our homestead and our life is improving with every long-awaited, well-thought-out improvement.

Pipe Dreams

Our microhydro system uses Energy Systems & Design's Stream Engine to harvest energy from the falling water. The penstock is about 900 feet of 6-inch-diameter PVC which snakes up the seasonal creek to give us 32 feet of "head," or vertical fall.

It took us 24 years to work up to our present microhydro configuration. When we first decided to tap the creek's energy, the pipe diameter we used was much smaller and the penstock shorter—about 600 feet. It takes two things to make a hydro turbine run: head (vertical drop) and flow. If you have a lot of one, you can get by with not very much of the other. With a total head of only 32 feet, we needed more water than the small pipe could efficiently carry without too much friction loss. The 6-inch pipe was a substantial earlier preretirement upgrade.

The original homemade hydro intake filter.

Kathleen Jarschke-Schultze

The first part of a microhydro penstock is separating the water from everything else that likes to float or gets swept downstream during a big storm runoff. How well you need to filter the water depends on the size of the turbine's nozzles, which are the narrowest part of the penstock.

Our creek doesn't have a lot of head to start with, and we were loath to lose any by using the most common method of piping the water from the creek, through a filter, and into a tank with the main pipeline exiting the bottom of the tank. Instead, we put the hydro intake right into the creek. Bob-O has tried a number of pipe intake designs, mostly of his own do-it-yourself ingenuity. The intake setup we have used since 2001 is a 3-foot length of 6-inch PVC pipe, a 45° elbow, and a PVC end cap. Three-eighths-inch holes are drilled every few inches along the pipe.

The unit was attached onto the upper end of the penstock, and worked well. It's fairly easy to clean out, and once the water level in the creek rises and a lot of the fallen leaves and other trash gets flushed out, it's self-cleaning. But accessing the intake was always an adventure—and required descent by rope. A knotted rope was looped over an overhanging branch. Holding onto the rope with one hand and holding a leaf rake in the other (our "high-tech" cleaning tool), one of us would descend into the creek, perched on the rocks and the hydro pipe. The rake was just long enough to reach the intake, and we could remove any leaves caught on the intake's holes. We didn't think much about doing that when in our 40s or 50s, but looking down the road a little bit, we decided that there had to be a better—and safer—way.


Kathleen Jarschke-Schultze

The new, improved (but still homemade) hydro intake filter.

Screen Star

Our most exciting retirement project yet was rebuilding the intake. Our creek is seasonal and so all this work needed to take place while the weather was hot and the creek dry.

Bob-O's microhydro intake redesign hinged on two things. First, it had to incorporate at least one of the 1/8-inch-thick aluminum fish screens he scavenged when the Bureau of Land Management upgraded a hydro intake on a river. Bob-O was installing the PV that would power the self-cleaning intake and the person in charge just wanted to get rid of the screens. Well, sure! Saved from the dump, they have waited in our boneyard for years. Second, the parts needed to be sourced from our boneyard if possible. Bob-O had spotted some sheet aluminum in assorted sizes.

The intake is a 36-by-20-inch box with a sloped top covered by the fish screen. Aluminum PV rack pieces, also from our boneyard, lend extra rigidity for both the box and the screen. Bob-O used stainless steel hardware throughout for corrosion resistance. The screen doesn't have to deal with any fish, as there are none in this seasonal creek. Our 6-inch penstock attaches to the outlet hole cut into the down-creek side of the intake. The box fills with water, which fills the pipe. The excess water flows over the screen, cleaning as it goes. The sides of the creek are built up with rocks to help channel the water over the intake box.

Before the new intake could be installed, the 6-inch PVC pipe needed to be extended about 60 feet. Although this gave us only another foot of drop, it also gave us a wide-open section of creek that was easier to access. Bob-O was also able to easily install a large valve in the pipe slightly downstream from the intake. The older we get, the more important easy maintenance of our off-grid systems becomes.

Mountain Microhydro, Mountain Mama

Once the trees drop their leaves in the fall, we know the creek will return. Then it is a matter of checking the hydro intake screen regularly to remove the leaves as they get sluiced down with the rising water. We now use a squeegee on a long handle to clean the screen.

The whole project took a couple of months to design and implement. Bob-O worked on it regularly between garden tilling and making trips to pick up horse manure in our dump trailer. With the creek dry, it was much easier to dig down into the creek bed to set the intake low, where the water would flow over it. Using a backhoe, he was able to prep the rock pad and maneuver the box into place.

When the creek began to flow again, we had to clean the screen fairly often, although not a lot of leaves remained on the screened top. In the winter, when the water level is higher and the creek runs faster, Bob-O's intake design really shows its utility. Practically no leaves or debris stay on the screen.

Our walks through the meadow and to the intake are now just to admire how well the new hydro intake works. When I told Bob-O it was a thing of beauty, he said I was no longer "marginally mountain," I was now a full-on mountain mama.

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Finding the Sweet Spot

All PV cells, modules, and arrays have conditions under which they will perform optimally. Two of the most important of those conditions—amount of sunlight and PV cell temperature—are difficult to control. Ambient temperatures and heat from sun's rays increase cell temperature, affecting how well a cell converts available light to electrical energy. To date, beyond providing an air gap behind an array, no practical, cost-effective means of cooling cells have been found. Our only recourse is to adjust the module's electrical condition.

Maximum power point tracking (MPPT) optimizes a module's power output within the range allowed by its temperature and available sunlight. Every PV module has particular characteristics that are described by I-V curves—a graphed representation of current (I, in amps) versus voltage (V). Power is a product of current and voltage (watts = amps × volts). While the curve changes based on temperature and sunlight, there is only one maximum power point (MPP) on an I-V curve.

Different electronic algorithms can achieve MPPT, but what all methods do is periodically vary electrical conditions and test power output. If the power increases, it is varied a little more until the maximum is attained. If the tested power decreases, then the condition is varied in the other direction to find that maximum power point. That "sweet spot" is maintained until it's time to again vary conditions and retest. A re-sweep of the I-V curve typically happens every few minutes or when there is a significant power change, though it can vary depending on the tracking method. Since the array is not operating at the MPP during the I-V curve testing, it makes sense to spend as little time as possible during the sweep.

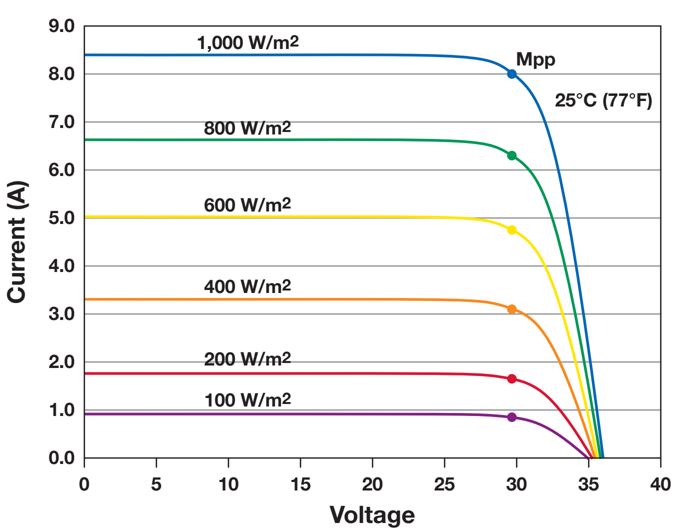
MPPT equipment also varies. Most batteryless grid-tied systems use string inverters, which test and adjust to the MPP for the entire array. Most battery-charging systems rely on a single MPPT charge controller to adjust the entire array. But no two PV modules share the exact characteristics—slight differences between I-V curves, cell temperature, and sunlight (including shading) vary from one place in the array to another. That's where module-level MPPT comes in.

Microinverters, which are paired to each module, do this automatically. But in a system with a central string inverter, a DC optimizer would be required for each module. A system using optimizers might enjoy an increase of a few percent up to 25% or more in power output, depending on shading and other specifics. A battery-based system would similarly benefit from optimizers. In the case of module-level MPPT, the expense of the equipment should be weighed against the potential gain in energy harvest. Each module will require an optimizer, which can add from a few to several hundred dollars to the system's overall cost. Optimizer implementation also adds complexity, installation time, and more points of potential failure.

Understanding what MPPT is (and what your equipment options are for various PV system types and scenarios) will help you make an informed choice for your particular situation.

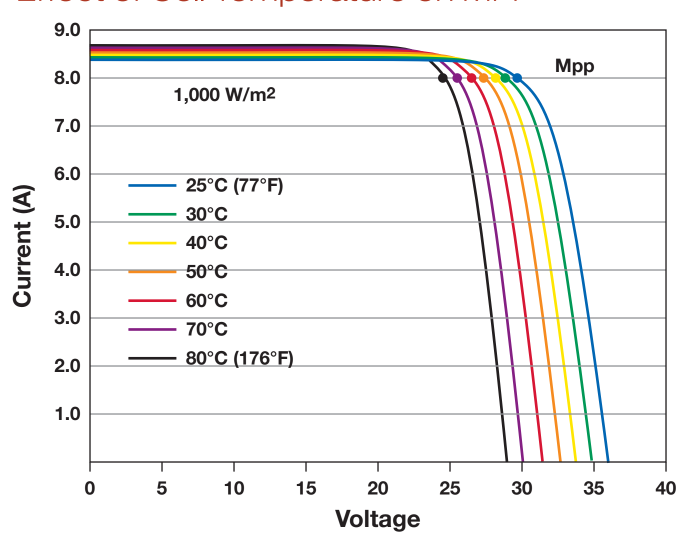
—Michael Welch

Insolation Effects on Maximum Power Point



Less sunlight on the module (due to clouds, shading, or dirt) reduces the amperage of the maximum power point (Mpp).

Effect of Cell Temperature on MPP



Higher cell-operating temperatures reduce the voltage (V) of the maximum power point (Mpp).

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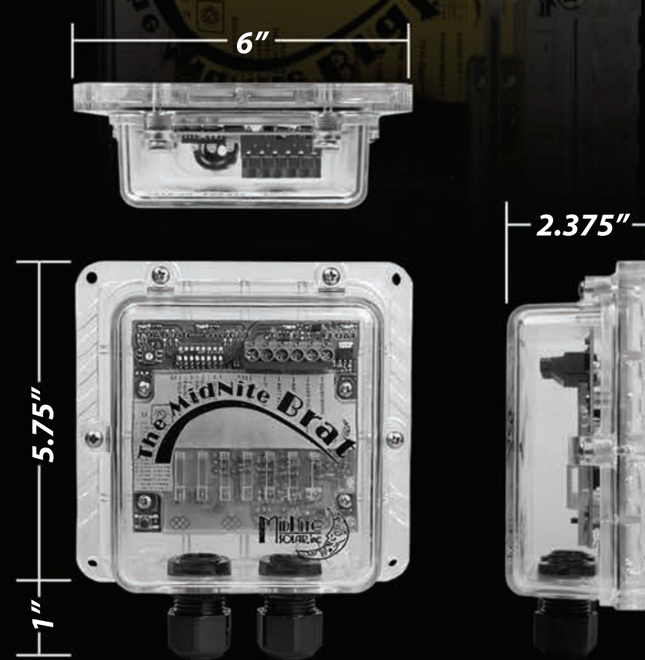

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